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**THERMAL ANALYSIS OF CONCEPTUAL
DESIGNS FOR GPHS/FPSE
POWER SYSTEMS OF 250 W. AND 500 W.**

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Final Report

By

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ABSTRACT

Thermal analyses were performed for two distinct configurations of a proposed space nuclear power system which combines the U.S. Department of Energy's (DOE) General Purpose Heat Source (GPHS) modules with state-of-the-art Free-Piston Stirling Engines (FPSE). The two configurations correspond to systems with power levels of 250 W_e and 500 W_e. The 250 W_e GPHS/FPSE power system utilizes four GPHS modules and one FPSE, and the 500 W_e contains eight GPHS modules and two FPSEs. The configurations of the systems and the bases for selecting the configurations are described. Brief introductory sections are included to describe the GPHS modules and free-piston Stirling engines.

The primary focus of the thermal analyses is on the temperature of the iridium fuel clad within the GPHS modules. A design goal temperature of 1573 K has been selected as upper limit for the fuel clad during normal operating conditions. The basis for selecting this temperature limit is discussed in detail.

Results obtained from thermal analysis of the 250 W_e GPHS/FPSE power system indicate fuel clad temperatures which slightly exceed the design goal temperature of 1573 K. The results are considered favorable due to the numerous conservative assumptions used in developing the thermal model and performing the thermal analysis. To demonstrate the effects of the conservatism, a brief sensitivity analysis is performed in which a few of the key system parameters are varied to determine their effect on the fuel clad temperatures. It is concluded that thermal analysis of a more detailed thermal model would be expected to yield fuel clad temperatures below the design goal temperature limit of 1573 K.

Thermal analysis of the 500 W_e GPHS/FPSE power system yields fuel clad temperatures slightly greater than those obtained in the analysis of the 250 W_e power system, yet still close enough to the design goal temperature limit to consider the results favorable. Analysis of a more detailed thermal model would be expected to yield fuel clad temperatures closer to, or lower than, the design goal temperature.

An additional analysis is performed for the 500 W_e GPHS/FPSE power system. Since the 500 W_e system has two Stirling engines, the effects on fuel clad temperatures of losing one engine are analyzed. It is found that the fuel clad temperatures rise significantly when one engine is lost. The results are not too unfavorable due to certain ambiguities associated with the design goal temperature limit.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and the role of the accounting department in ensuring the integrity of the financial statements. It also highlights the need for regular audits and the importance of transparency in financial reporting.

2. The second part of the document focuses on the implementation of internal controls to prevent fraud and ensure the accuracy of financial data. It outlines the key components of a robust internal control system, including segregation of duties, authorization procedures, and regular monitoring and evaluation.

3. The third part of the document addresses the challenges faced by organizations in managing their financial resources effectively. It discusses the importance of budgeting, forecasting, and financial analysis in making informed decisions and optimizing resource allocation.

4. The fourth part of the document explores the role of technology in modern accounting and finance. It highlights the benefits of using accounting software and digital tools to streamline processes, improve accuracy, and enhance data security.

5. The fifth part of the document discusses the importance of ethical considerations in financial management. It emphasizes the need for integrity, honesty, and transparency in all financial transactions and the role of the accounting department in ensuring compliance with ethical standards.

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1.0 INTRODUCTION

This report presents the results of a thermal analysis performed by the University of Florida's Department of Nuclear Engineering Sciences for NASA Lewis Research Center (Contract # NAG3-1123). The primary intent of this study is to demonstrate by thermal analysis the feasibility of developing radioisotope-fueled dynamic space power systems of 250 W_e and 500 W_e which combine the U.S. Department of Energy's (DOE's) General Purpose Heat Source (GPHS) modules with state-of-the-art Free-Piston Stirling Engines (FPSE). Feasibility of each system is based solely on meeting the temperature constraints for the radioisotope fuel clad under normal operating conditions. Other general design criteria, such as requirements for specific mass (kg/kW_e) and structural design, are given consideration in this study, but can be addressed in full detail only as design of the system progresses beyond the conceptual stage.

2.0 OBJECTIVES

2.1 Overview

This study consisted primarily of the performance of thermal analyses of the proposed GPHS/FPSE power systems using thermal models representative of the system configurations at power levels of 250 W_e and 500 W_e. Development of the thermal models and the results of the thermal analyses performed with these models are described in this report. The thermal models were created using NASA's thermal analysis computer codes, TRASYS and SINDA. These codes were used together to generate the steady-state temperature distribution throughout the enclosures of the power generation systems, including the interior components of the GPHS modules.

The primary focus of the thermal analysis with the thermal models is the temperature of the iridium fuel clad in the GPHS modules. Temperature constraints and other design considerations are addressed in detail in the following subsections.

2.2 Temperature Constraints

The temperature limits are imposed on the clad to ensure the integrity of the fuel capsule in the event of an aborted mission in which the GPHS modules reenter the earth's atmosphere and impact the surface. For the clad fuel pellet to survive impact, the iridium clad must retain its ductility. To ensure adequate ductility, the fuel capsules must

impact with a relatively high clad temperature and a reasonably fine grain size. The fine grain size can be assured only if the fuel clad temperature during normal operating conditions has been below a prescribed temperature limit and the peak reentry temperature of the clad has also been below a specified temperature limit.

To meet the temperature requirements of the iridium clad in the GPHS/FPSE power system, there are two primary design concerns: (1) under normal operating conditions, the iridium clad temperature must be below the maximum allowable, and (2) the system must be designed such that, upon accidental reentry, the power system will break apart, allowing the GPHS modules to reenter the atmosphere individually. Design considerations associated with this second concern are given in the next section.

The first design concern, the maximum permissible temperature for the iridium clad under normal operating conditions, was initially thought to be straightforward. The temperature limits of the clad for normal operating conditions and for extended transient conditions were identified in a 1986 Rockwell International Corporation BSTS (Boost Surveillance and Tracking System) power system definition study (reference 1). These temperature limits, given in Table 2.1, are almost identical to, but slightly more conservative than, the initial temperature constraints used in the design of the GPHS modules (reference 2). The requirements given in Table 2.1, although slightly ambiguous, were interpreted to impose the following fuel clad temperature limits: (1) a maximum of 1300° C for normal operation and (2) a minimum of 950° C for reentry and earth impact. The temperature

ranges listed for transient conditions would only apply to the GPHS/FPSE system if mission lifetimes for the power system were to be within the time intervals listed for 'transient' conditions.

Table 2.1 GPHS Temperature Design Requirements [1]

*PICS, operational	1300° C or less maximum long term
*PICS, impact	950° C minimum
Transient	Time at temperature (hours)
1600 to 1500° C	10
1500 to 1400° C	50
1400 to 1300° C	1000
1300 to 1200° C	100,000
1200 and below	indefinite

* Post-Impact Containment Shell [Iridium Fuel Clad]

The temperature limits used for design of the GPHS modules are given in reference 2 as: (1) a maximum of 1330° C for normal operation, and (2) 900° C for minimum impact temperature. In addition, a peak reentry temperature limit of 1800° C was also imposed.

The temperature limits interpreted from Table 2.1 seemed reasonable and were to be used as the design goal temperatures for the detailed thermal analysis. However, while on a trip to Mound Laboratories in Dayton, Ohio, where the GPHS blocks are assembled and tested, the Mound engineers expressed skepticism concerning the validity of these

numbers. The minimum impact temperature was agreed upon as 950 °C, but, the Mound engineers stated that the GPHS modules could be safely operated for extended periods (anticipated mission lifetimes) in the temperature range of 1573 K \pm 200 K (1100 °C to 1500 °C, 2012 °F to 2732 °F). Grain growth in the iridium clad, they suggested, had been overestimated when the temperatures limits listed in Table 2.1 were established.

Using the temperature limits as recommended by the Mound engineers would lead to much more flexibility in design of the GPHS/FPSE system. For example, a power system configuration with fuel clad temperatures of up to 1500 °C would be allowed to operate for an indefinite period. If the values in Table 2.1 were used as the design criteria, the blocks could be operated with a clad temperature of 1500 °C for only 50 hours.

Due to this confusion, the Astro Space Division of the General Electric Company (GE), which performed the Safety Analysis for the Galileo mission (which uses the GPHS-RTG), was contacted for their advice. According to Mr. John Loffreda of GE, there is an ongoing debate as to the effect on grain growth in the iridium clad of long term operation within the temperature ranges given in Table 2.1. Some feel that these temperature limits are conservative, and the GPHS blocks may be operated safely for longer periods in these temperature ranges. Others feel that there would be too much grain growth when adhering to these temperature constraints. The concerns, however, are more with the higher temperature ranges and the associated times of operation. Operation of the GPHS modules with the iridium clad temperature at or near the maximum long term operational

temperature limit of 1300°C given in Table 2.1 is perfectly acceptable for indefinite operation. Thus, the design goal of this study is to produce thermal models of the GPHS/FPSE power systems which can be shown by thermal analysis to have iridium clad temperatures of 1300°C (1573 K , 2372°F) or below under normal, steady-state operating conditions.

2.3 Other Design Considerations

In developing the configurations for the GPHS/FPSE power systems, three design considerations were followed in addition to the primary objective of meeting the clad temperature requirement for normal operation. They are listed below with brief explanations.

(1) Structural design. Configuration of the power systems must allow for supports for the GPHS blocks (to be added to the design later) to fail upon reentry, allowing the GPHS blocks to reenter the atmosphere individually. This condition assures that temperature requirements are met for reentry and earth impact.

(2) Overall size of the power system enclosure. The power system enclosure for each configuration, consisting of the GPHS blocks, heat sink, structural supports, and multifoil insulation must be as small as possible to reduce the specific mass of the system.

(3) Symmetry. The GPHS modules must be arranged symmetrically without any large gaps to ensure uniformity of the heat flux into the heat sink. Uniformity of the heat flux into the Stirling engine heater head is critical to the successful operation of the free-piston Stirling engine.

Steps taken to ensure that these design considerations are followed are addressed in this report. The system configurations are described in Section 3.0. The GPHS modules and FPSE are described in Sections 4.0 and 5.0, respectively. Thermal modeling and analysis of the 250 W_e GPHS/FPSE power system are described in Sections 6.0 and 8.0, respectively. Thermal modeling of the 500 W_e GPHS/FPSE power system is described in Section 7.0 and results of the thermal analysis of the 500 W_e system are given in Section 9.0.

2.4 References

1. Brandewie, Dr. R., et al., "Lockheed Missiles And Space Company BSTS Power System Definition Study", Rockwell International Report #RI/RD86-188 Rev. 1, 1986.
2. Schock, A., "Design Evolution and Verification of the 'General Purpose Heat Source'," Proceedings of the 15th IECEC, Seattle, Washington, August, 1980.
3. Conversations with EG&G engineers at Mound Laboratories in Dayton, Ohio on February 6th, 1990.
4. Conversation with John A. Loffreda of General Electric Company's Astro Space Division on February 22, 1990.

3.0 GPHS/FPSE POWER SYSTEM CONFIGURATIONS

3.1 Introduction

For power levels of 250 W_e and 500 W_e , the basic configurations of the GPHS/FPSE systems used for thermal modeling and analysis are described in this section. The descriptions are very general. Detailed descriptions of each configuration and the bases for selecting these two configurations are included in Sections 6.0 and 7.0 where the thermal models for each system are described. Specific characteristics of the components, such as materials and thermal properties, are covered in the thermal analysis sections of this report.

3.2 The 250 W_e GPHS/FPSE Power System

3.2.1 Introduction

The general configuration for the proposed GPHS/FPSE 250 W_e power system is shown in Figures 3.1a and 3.1b. As indicated in the figures, the system contains a cylindrical heat sink (to simulate the FPSE heater head) surrounded by four GPHS modules, all encased in an insulated cylindrical outer structure. Since each GPHS block generates approximately 250 thermal watts, the total thermal power of the system is 1000 W_{th} .

An overall system efficiency of 25% has been assumed in order to produce 250 W_e . This

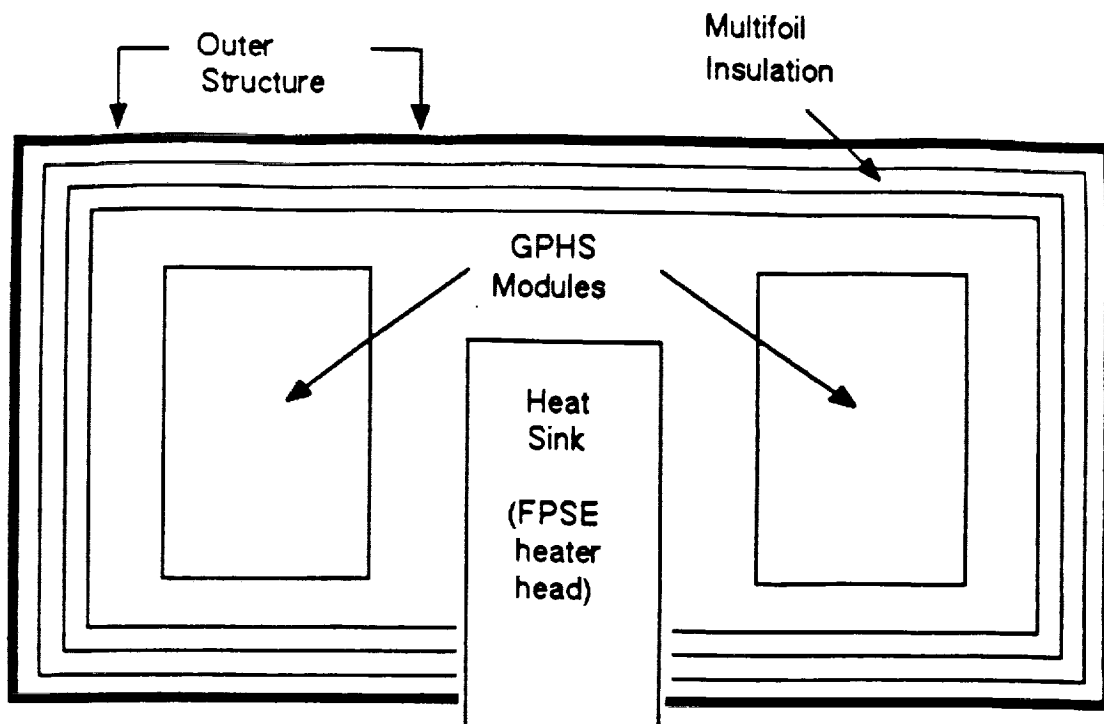


Figure 3.1a Side View of 250 W(e) GPHS/FPSE Power System

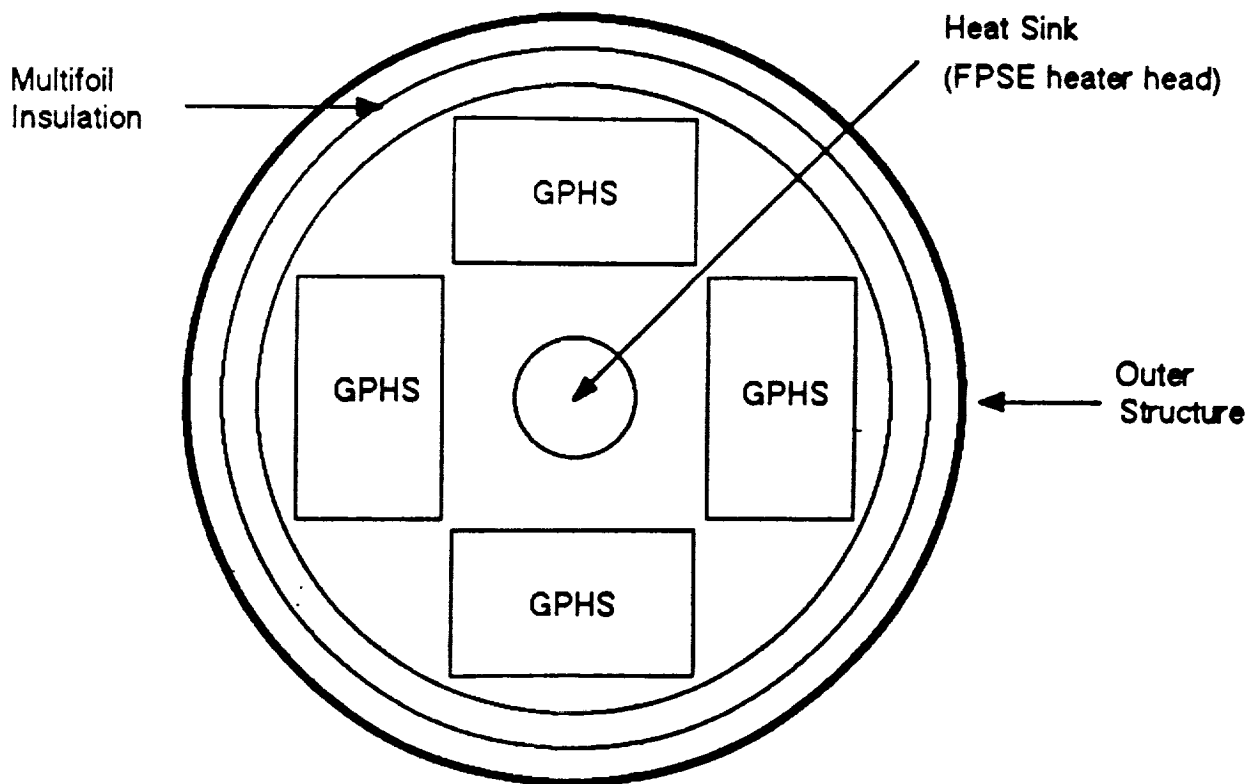


Figure 3.1b Top View of 250 W(e) GPHS/FPSE Power System

assumption is based upon discussions with engineers in NASA Lewis Research Center's (LeRC's) Power Systems Integration Office and Stirling Technology Branch. The 25% efficiency value is consistent with the design system efficiency for the 1.5 kW_e Solar Dynamic Space Experiment (SDSE).

The power level is comparable to that of the GPHS-RTG (General Purpose Heat Source - Radioisotope Thermoelectric Generator) which has a beginning-of-life output power of approximately 285 W_e. As design of the GPHS/FPSE system progresses, a comparison to the GPHS-RTG will be made based upon specific mass.

The power system components and their positioning with relation to each other are described below.

3.2.2 Configuration Description

The heat sink is centrally located at one end of the power system enclosure. It is cylindrically shaped with a radius of 1.0 inch and a length of 3.0 inches. The heat sink has a constant surface temperature of 1050 K. At the end of the cylindrical heat sink is a flat disk-shaped end cap which is thermally insulated from the heat sink. The disk is not considered a part of the heat sink. The basis for the heat sink design is given in Section 6.0 as part of the detailed description of the thermal model.

The GPHS modules are positioned symmetrically around the heat sink. The modules

have dimensions of 3.826 inches (width) X 3.668 inches (height) X 2.090 inches (depth). Their largest surfaces (3.826 inches X 3.668 inches) face toward the heat sink with the height parallel to the length of the heat sink. The shortest radial distance between the heat sink and the GPHS modules is 1 inch. The modules are assumed to be 0.5 inches from both the top and the bottom of the enclosure. Thus, the modules are suspended in this configuration, and do not physically contact any other surfaces. The half inch gap is provided to allow for structural support which will be added later in the system design. The shortest edges of the GPHS blocks (2.090 inches) extend away from the heat sink.

The cylindrical outer structure is internally lined with multifoil insulation and contains the heat sources and the heat sink. The inner surface of the power system enclosure (the inner-most foil of the insulation) is cylindrically shaped with a radius of 4.8 inches and a length of 4.668 inches. The thickness of the foil and the external dimensions of the system will be determined as design of the system continues.

3.3 The 500 W_e GPHS/FPSE Power System

3.3.1 Introduction

As shown in Figures 3.2a and 3.2b, the general configuration for the 500 W_e GPHS/FPSE power system is very similar to the configuration described in the previous subsection for the 250 W_e system. Due to the increase in power level, however, there are a couple of

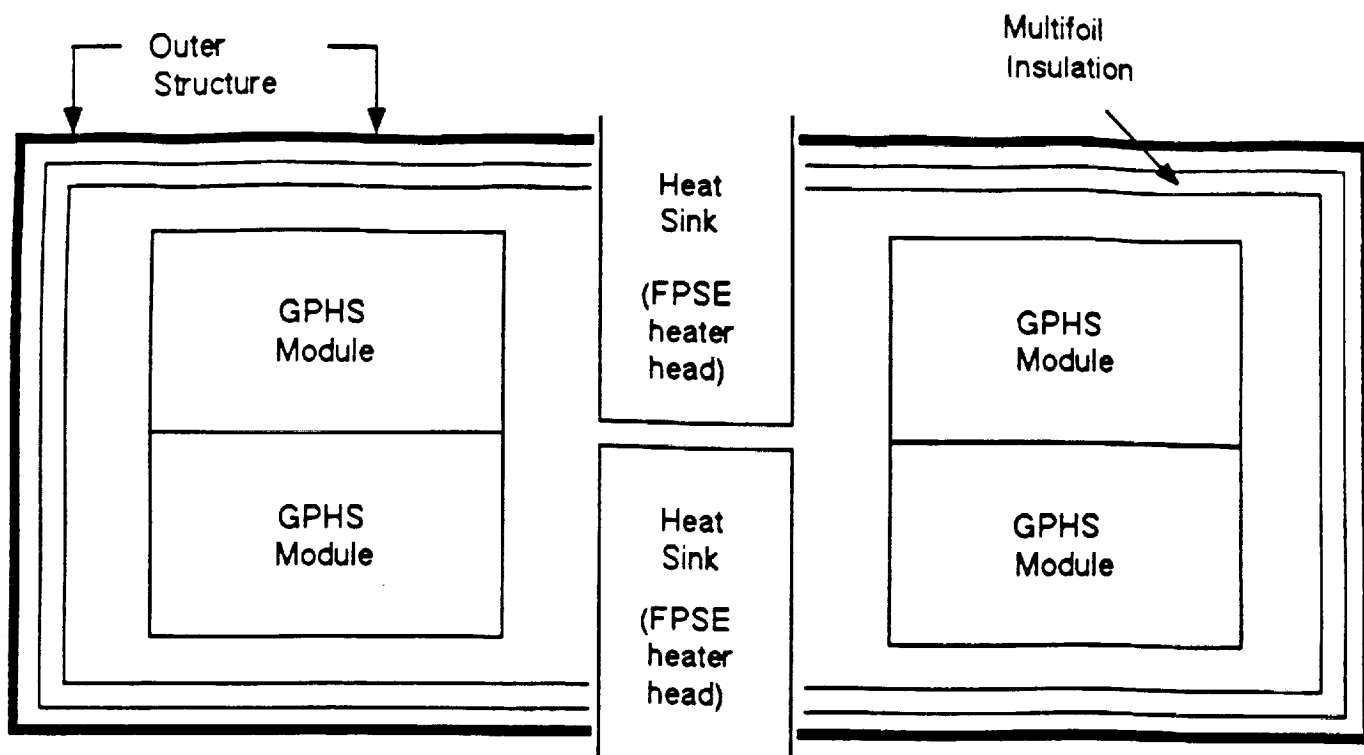


Figure 3.2a Side View of 500 W(e) GPHS/FPSE Power System

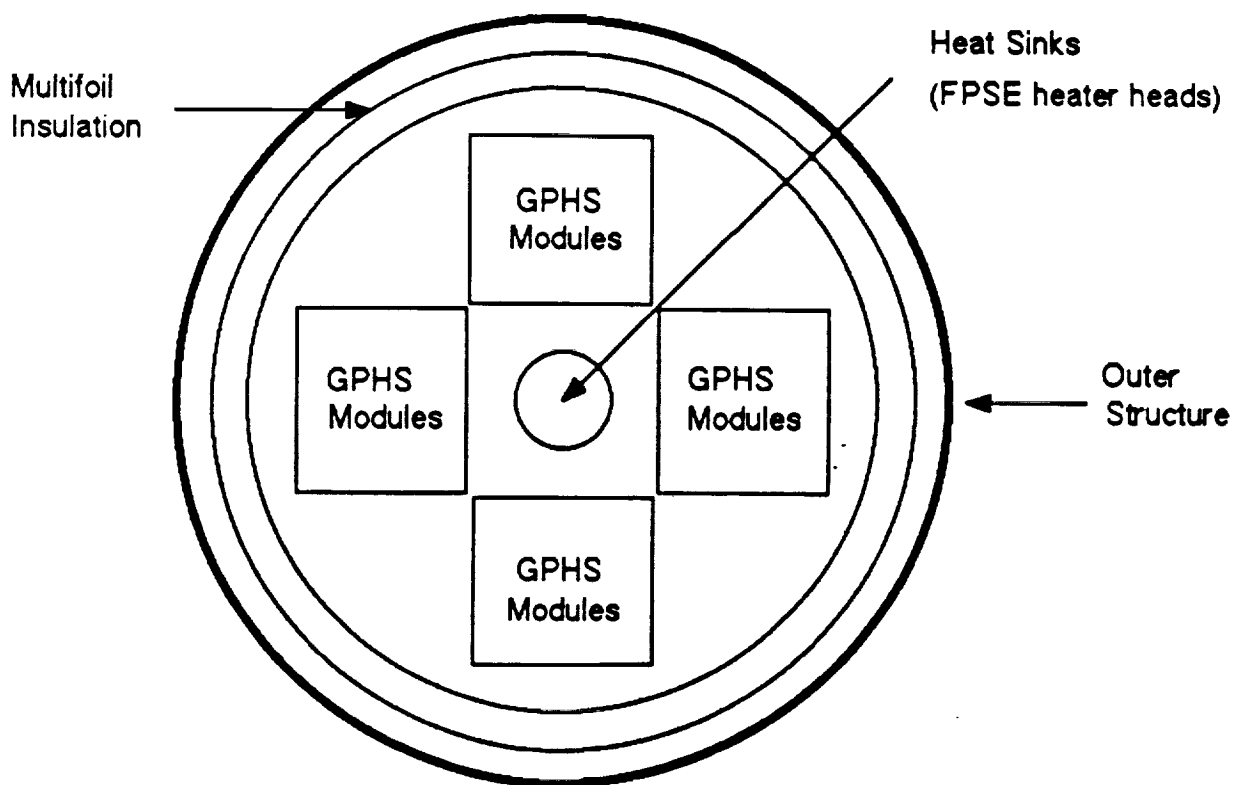


Figure 3.2b Top View of 500 W(e) GPHS/FPSE Power System

differences. Instead of having only one heat sink, this system utilizes dual, opposing heat sinks which represent two opposing FPSE heater heads. In addition, eight GPHS modules are required to supply 2000 watts of thermal energy. As with the 250 W_e system, an overall system efficiency of 25% has been assumed.

3.3.2 Configuration Description

The cylindrical heat sinks in the 500 W_e power system are similar but not identical to the one in the 250 W_e system. The radius of each sink is the same (1.0 inch) but in the 500 W_e configuration, the heat sinks have lengths of only 2.5 inches. This provides for the most compact configuration. Since the distance between the two ends of the enclosure is 5.18 inches, the ends of the heat sinks are separated by only 0.18 inches.

The heat sinks are centrally located at each end of the power system enclosure. The cylinder surfaces have a constant temperature of 1050 K. Like the heat sink in the 250 W_e system, a flat disk-shaped end cap is located at the end of each heat sink cylinder. The end caps are thermally insulated from the heat sinks. The basis for the heat sink design is given in Section 7.0 as part of the detailed description of the thermal model.

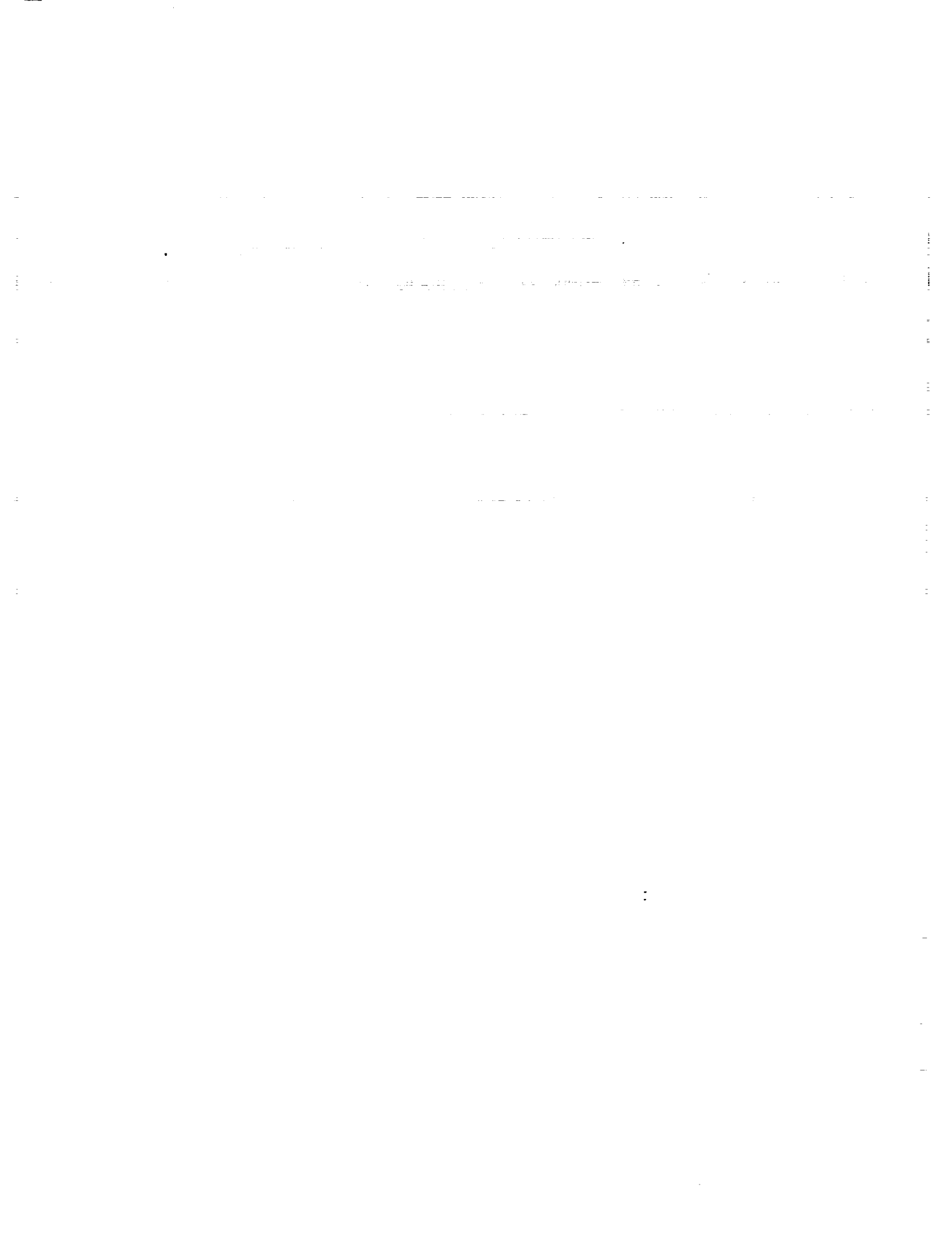
The eight GPHS modules are stacked symmetrically around the heat sinks in four sets of two (See Figures 3.2a and 3.2b). Each set of two can be viewed as a single block with dimensions of 3.826 inches (width) X 4.180 inches (height) X 3.668 inches (depth). The largest surfaces (3.826 inches X 4.180 inches) of each stack face the heat sinks

with the height of each stack parallel to the lengths of the heat sinks. The shortest radial distance between the heat sink surface and the GPHS modules is 1.0 inch. A gap of 0.5 inches is left between the blocks and the ends of the enclosure to allow for support structures to be added later in the system design. The shortest edges of the stacks of GPHS modules (3.668 inches) extend away from the heat sink.

The cylindrical outer structure is internally lined with multifoil insulation and contains the heat sources and the heat sink. The inner surface of the power system enclosure (the inner-most foil of the insulation) is cylindrically shaped with a radius of 6.5 inches and a length of 5.18 inches. The actual thickness of the foil and the external dimensions of the system will be determined as design of the system continues.

3.4 References

1. Schreiber, J., et al., "SDSE Summary," NASA Lewis Research Center, Cleveland, Ohio, Summer, 1989.



4.0 GENERAL PURPOSE HEAT SOURCE

4.1 General Description

The General Purpose Heat Source (GPHS) module is a block-shaped hexahedron with overall dimensions of 9.317 cm X 9.718 cm X 5.308 cm (3.668 in. X 3.826 in. X 2.090 in.) and a mass of approximately 1.45 kg (3.2 lb). Each module contains four iridium clad fuel pellets, two graphite impact shells, two thermal insulation sleeves, and an outer aeroshell. Initially each block generates 250 ± 6 watts of thermal energy. Each GPHS module is completely autonomous including its own passive safety provisions. The internals of the blocks are illustrated in Figure 4.1. The major components are described in the following subsections.

4.2 Fuel Pellet

Each GPHS module contains four radioisotope fuel pellets (see Figure 4.1). The solid ceramic pellets are cylindrically shaped with an average diameter of 2.753 ± 0.025 cm (1.084 ± 0.010 inch) and an average length of 2.756 ± 0.038 cm (1.085 ± 0.015 inch). The fuel material is an isotopic mixture of plutonium in the form of the dioxide, PuO_2 , containing $83.5 \pm 1\%$ $^{238}\text{PuO}_2$. Each pellet contains an initial thermal inventory of 62.5 ± 1.5 watts which corresponds to 1921 ± 46 Curies of ^{238}Pu and 152.4 ± 3.7 grams of PuO_2 per pellet. Heat transfer properties of the fuel are included in Appendix A.

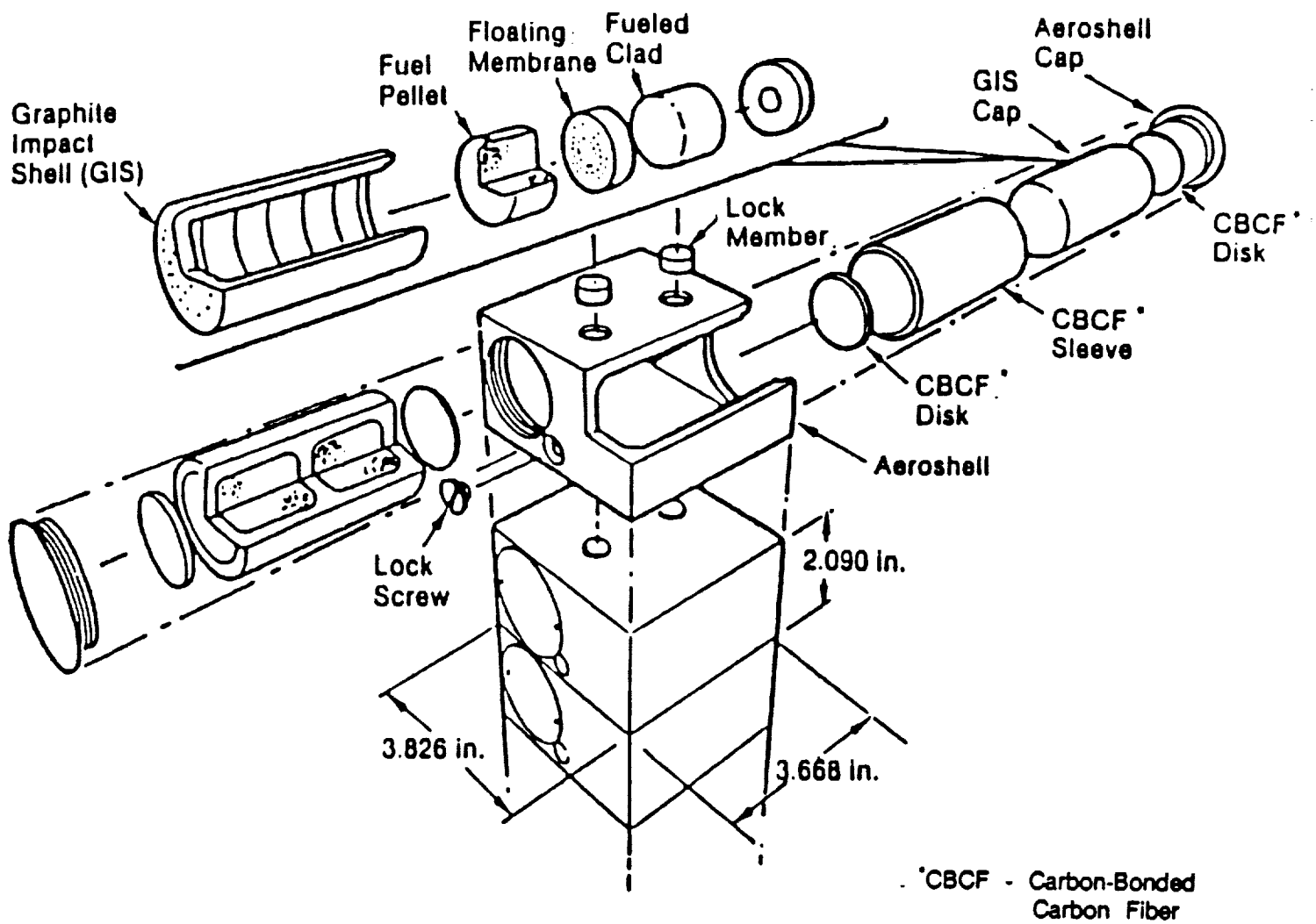


Figure 4.1 General Purpose Heat Source Module

4.3 Clad Material

From a nuclear safety perspective, the clad material is the most important feature of the GPHS module. The clad's primary function is to prevent the release of radioactive material under all anticipated operating and accident conditions. Such conditions include ground transportation and handling, launch operations, launch, ascent and orbital insertion, on-orbit operations, and reentry, impact, and post-impact environmental behavior. In order to perform its intended function, two primary technical objectives had to be satisfied: (1) the clad must be chemically compatible with the fuel material and the surrounding Graphite Impact Shell (GIS) in all anticipated environments; and (2) the clad must be resistant to long-term air oxidation at elevated temperatures after surviving reentry and earth impact.

The clad material chosen for use in the GPHS is the iridium alloy, DOP-26 Ir, developed by Oak Ridge National Laboratories. This alloy was already known to be compatible with PuO_2 and the GIS, and it had the best chance of meeting the second technical objective. Meeting the second objective was difficult due to temperature constraints imposed on the clad in order for it to retain adequate ductility to survive earth impact (See Section 2.2).

The clad surrounds the fuel pellet with a minimum thickness of 0.0559 cm (0.022 inches). At one end of the fueled clad is a vent hole with a diameter of 0.04445 cm (0.0175 inches) and a vent hole filter subassembly which allows the helium gas to escape but prevents the release of particles from inside the fuel pellet.

Heat transfer properties of DOP-26 Ir can be found in Appendix A.

4.4 Graphite Impact Shell (GIS)

As shown in Figure 4.1, there are two GIS's per GPHS module. Each GIS contains two iridium clad fuel pellets separated by a floating membrane. The GIS has a threaded end cap to secure its contents. The GIS, the floating membrane and the end cap are all constructed of fine weave pierced fabric (FWPF) graphite. FWPF is a composition of carbon-bonded carbon fibers which are layered to form a relatively dense, three dimensional structure. The cylindrical sides of the GIS have a density of 123.8 lb/ft^3 (1.98 g/cm^3). FWPF is extremely tough and has excellent thermal-shock resistance. The thermal conductivity and emissivity are anisotropic as indicated in Appendix A.

The GIS is designed to absorb energy and cushion the fuel capsule under earth impact conditions associated with GPHS module terminal velocity. The GIS also provides a protective shell against shrapnel which may penetrate the aeroshell and the CBCF sleeve.

4.5 CBCF Disk and Sleeve

Surrounding each GIS is a thermal insulating sleeve constructed of the carbon-bonded carbon fiber, CBCF-3. Developed by Oak Ridge National Laboratory, CBCF-3 has a density of only 14.4 lb/ft^3 (0.23 g/cm^3) and has a very low thermal conductivity normal to its deposition plane (see Appendix A). At each end of the GIS is an insulating disk made of the same material.

The primary function of the insulator is to prevent overheating of the fuel capsule during hypersonic reentry and overcooling during subsonic descent. It also provides protection against the heat from launch pad fires.

4.6 Aeroshell

Four clad fuel pellets enclosed in two GIS's and surrounded by the thermal insulators are housed in the outer aeroshell as shown in Figure 4.1. Each of the two assemblies is held in place by an aeroshell cap and a lock screw. All aeroshell components are constructed of the same material as the GIS, FWPF graphite. Physical properties of the aeroshell FWPF graphite are included in Appendix A.

The aeroshell is the primary structural member of the GPHS module. Its primary function is to provide ablation protection during reentry, thus protecting the GIS's from the harsh environment encountered during reentry. It also serves as the outermost protective layer against shrapnel in the event of an explosion.

4.7 Nuclear Safety

Each heat source module contains its own passive safety provisions to immobilize the fuel under all credible accident conditions. The most severe accident would be atmospheric reentry followed by earth-impact. In order to guarantee containment of radioactive material after earth-impact, the design of the blocks requires the modules to reenter the atmosphere individually. Any power system design which incorporates the GPHS

modules must allow for individual reentry.

Under all normal and accident conditions, there are two primary barriers to the release of radioactive material from the GPHS blocks. The first barrier is the ceramic fuel capsule itself. The ceramic material retains all solid decay products. The second barrier is the fuel clad with its vent hole filter subassembly which allows the escape of only the helium gas generated from the alpha decay. As discussed in earlier sections, the GPHS modules have been designed and tested to ensure that these two barriers prevent the release of radioactive material under all normal operating conditions and in all postulated accident and post-accident environments.

4.8 References

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3. Final Safety Analysis Report For The Galileo Mission, Prepared for the U.S. Department of Energy by General Electric's Astro-Space Division Under Contract DE-AC01-79ET32043, May, 1988.
4. Glasstone, S., Sesonske, A., Nuclear Reactor Engineering, Third Edition, Van Nostrand Reinhold Company, New York, 1981.
5. Brandewie, Dr. R., et al., "Lockheed Missiles And Space Company BSTS Power System Definition Study," Rockwell International Report # RI/RD86-188 Rev. 1, 1986.

5.0 FREE PISTON STIRLING ENGINE

5.1 Introduction

For the purpose of the thermal analysis of the proposed GPHS/FPSE system, the Stirling engine is treated primarily as a heat sink which makes efficient use of the heat supplied from the decay of plutonium-238. When the system reaches the development phase, the cylindrically modeled heat sink may actually be a set of heat receptor fins, heat pipe(s) or the Stirling engine heater head itself. In any case, as development of this power system continues, the goal remains the conversion of the heat from radioactive decay to useful electrical output by a Free-Piston Stirling Engine (FPSE).

5.2 FPSE General Description

The FPSE is essentially a thermally driven mechanical oscillator which derives its power from the heat flow between a heat source and a heat sink. Using the Stirling cycle, the FPSE operates with the highest thermal efficiency of all known heat engines.

The three basic components of a FPSE are: (1) a relatively massive piston (the power piston), (2) a low mass piston (the displacer), and (3) a hermetically sealed cylinder. A typical configuration of a FPSE is shown in Figure 5.1.

The FPSE is chosen because the current technology status indicates that a light weight,

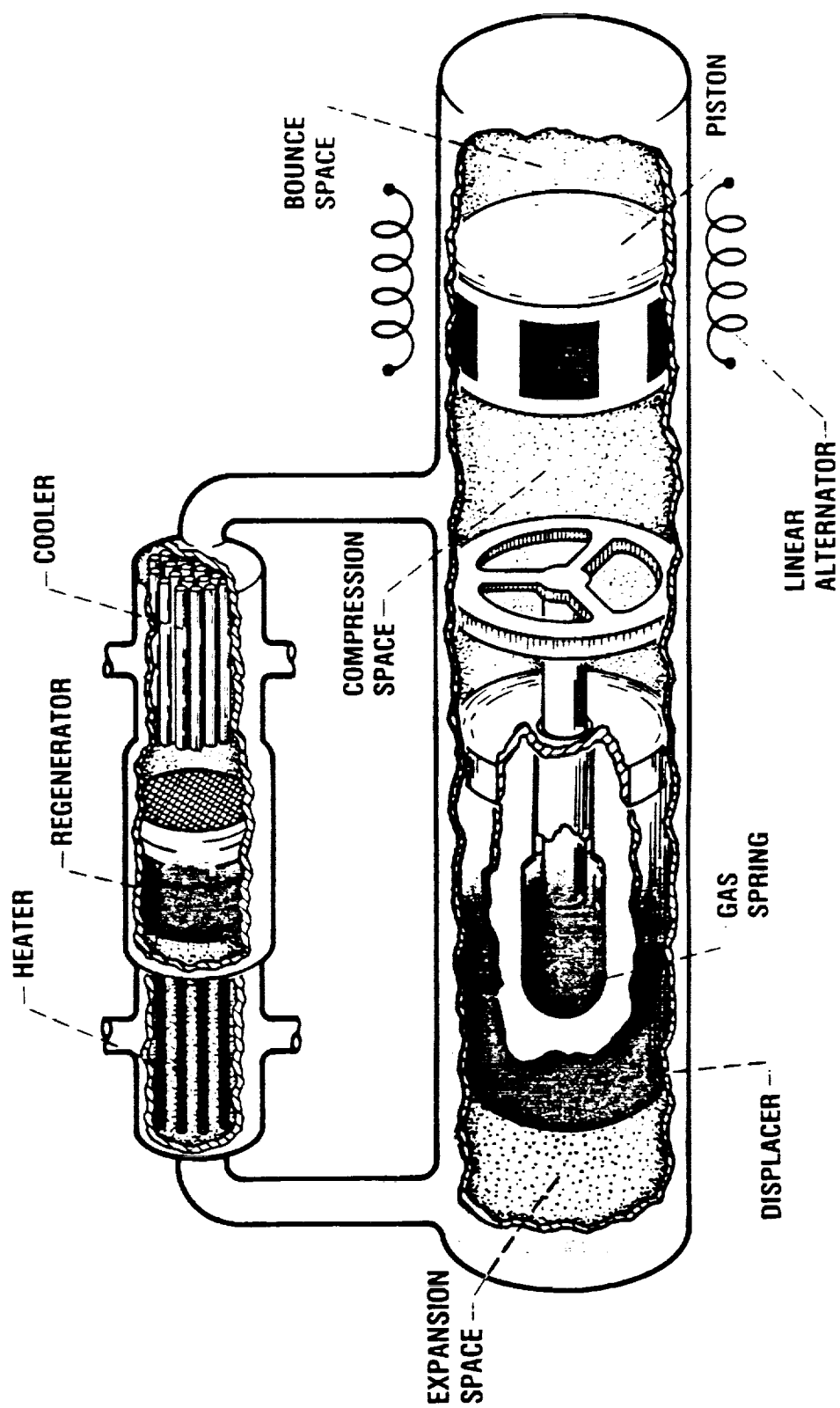


Figure 5.1 Free-Piston Stirling Engine With Linear Alternator

high efficiency, maintenance-free engine may be developed in the near future. The expected reliability of the FPSE is significantly higher than other dynamic conversion systems due to several unique features. Operating in a hermetically sealed cylinder, the FPSE has no mechanical linkages, no high pressure shaft seals and no contaminating lubricants; all of which tend to increase the probability of failure in a dynamic system.

5.3 References

1. Angelo, Jr., Ph.D., J.A., Buden, D., Space Nuclear Power, Orbit Book Company, Inc., Malabar, Florida, 1985.

6.0 THERMAL MODEL OF THE 250 W_e GPHS/FPSE POWER SYSTEM

6.1 Introduction

A general description of the 250 W_e GPHS/FPSE power system was given in Section 3.0. In this section, the detailed thermal model used for the thermal analysis is described. The bases for selecting the specific dimensions and physical properties for each of the nodes representing the power system components are given and the thermal connections between the nodes are also described. Figure 6.1 depicts the power system configuration including the components and their dimensions. Nodes of interest in the thermal analysis are identified in Figure 6.2.

The dimensions and physical properties associated with the nodes are given in Tables 6.1 and 6.2 for the heat sink cylinder nodes, Table 6.3 for the exterior GPHS module nodes, and Table 6.4 for the power system enclosure nodes. Nodes representing the fuel clad in the GPHS modules are described in Section 8.0 of this report. Additional information regarding the nodes representing the interior of the GPHS modules is given in Appendix B. Deep space, the external heat sink, is represented by a single boundary node (node # 99999) with a constant temperature of 0 K (-460 °F).

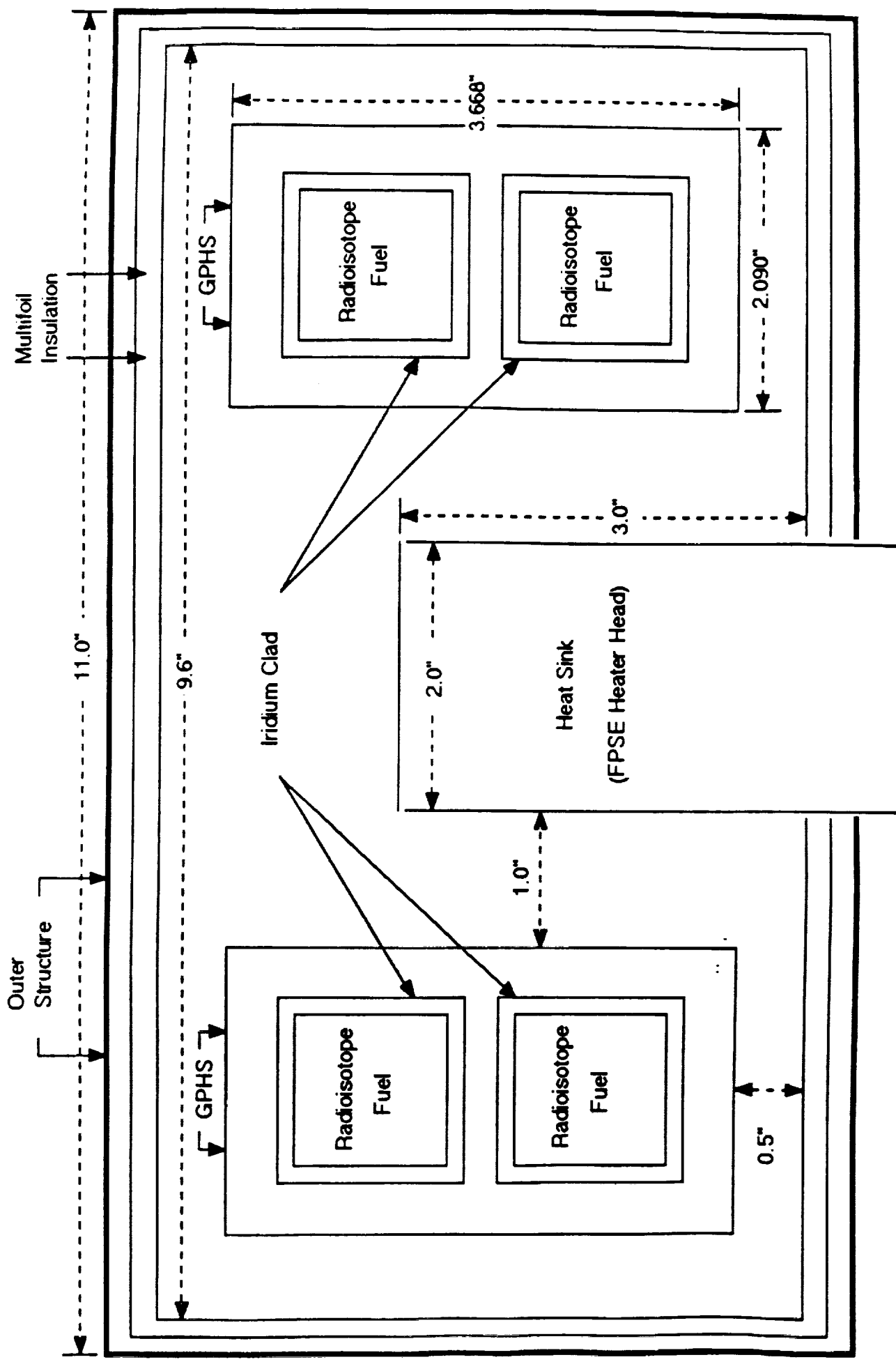


Figure 6.1 250 W(e) GPHS/FPSE Power System Configuration

6.2 Thermal Modeling of the Components

6.2.1 Heat Sink

6.2.1.1 Nodal Descriptions

The heat sink is situated at the center of one end of the power system. It is represented by a single cylindrical boundary node with a diameter of 2.0 inches, a length of 3.0 inches, a constant surface temperature of 1050 K, and an emissivity of 0.8.

At the end of the heat sink cylinder is a single arithmetic node (zero thermal capacitance) with a disk shape. This end cap has a diameter of 2.0 inches and an emissivity of 0.2. The end cap has not been assigned a thickness and it is thermally insulated from the heat sink. The heat sink cylinder and end cap nodal characteristics are summarized in Table 6.1.

Table 6.1 Heat Sink and End Cap Nodes

Node Number	Node Type	Node Shape	Dimensions (inches)	Emissivity
10100	Boundary	Cylinder	Radius: 1.0 Length: 3.0	0.8
10200	Arithmetic	Disk	Radius: 1.0	0.2

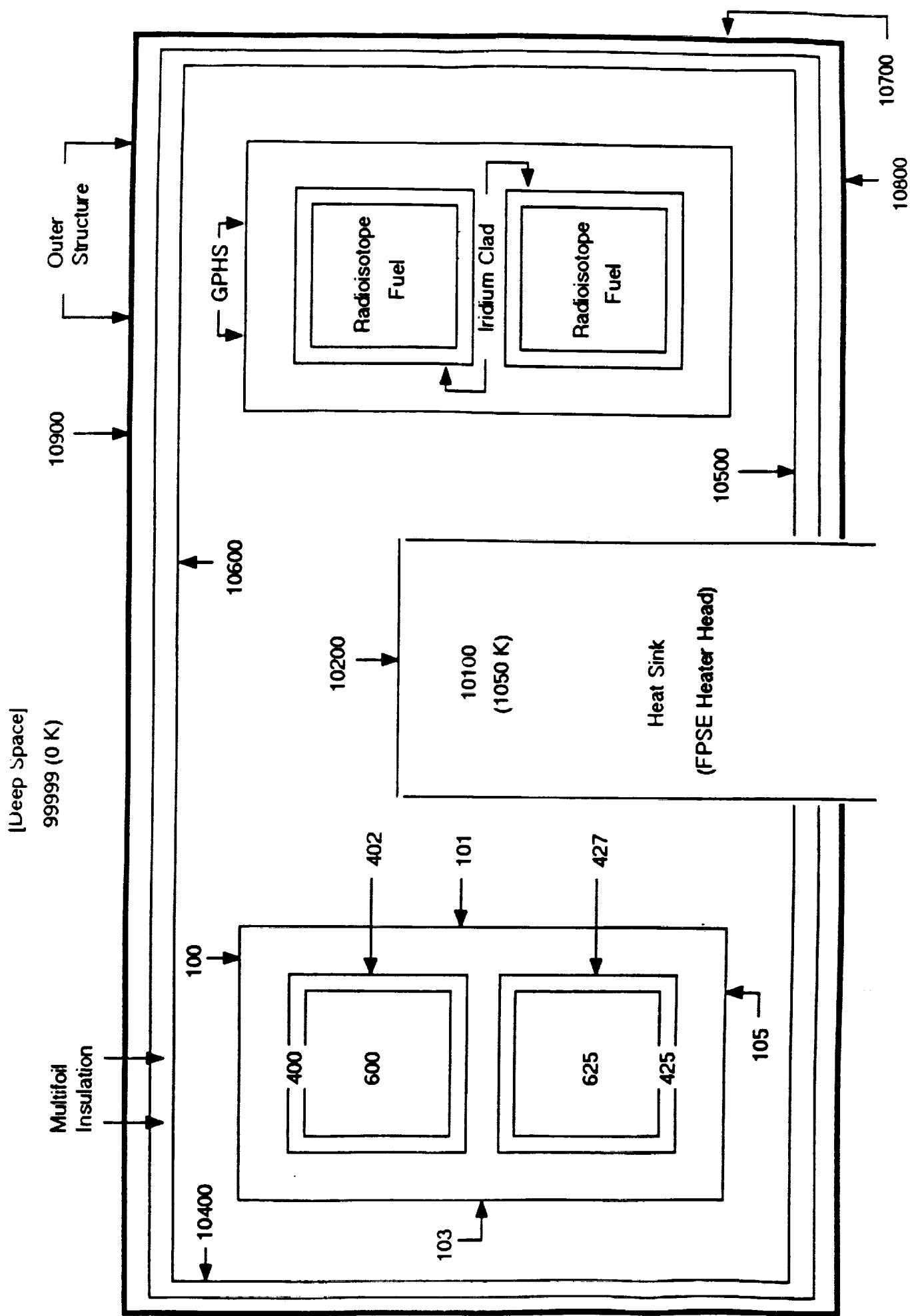


Figure 6.2 250 W(e) GP/FPSE Power System Nodal Arrangement

6.2.1.2 Basis for Heat Sink Parameters

The heat sink was initially to be modeled with heat entering through the sides and the end of the heat sink cylinder. The disk-shaped end cap was originally represented by a constant temperature boundary node. However, after discussion with Mr. Jeff Schreiber of NASA Lewis Research Center's (NASA LeRC's) Stirling Technology Branch, it was decided that this initial model would not be very accurate. He suggested that it would be more accurate to assume that heat enters only through the sides of the cylinder.

The basis for this assumption lies in the performance of the Stirling engine. If, in the final design of the GPHS/FPSE system, the heat sink is in fact a Stirling engine heater head, the performance of the engine would suffer considerably if heat were absorbed through the end of the heater head. The reasons for this drop in performance are beyond the scope of this project. Thus, in the thermal model, the flat disk representing the end of the heat sink is treated as an arithmetic node which is thermally insulated from the heat sink. The disk has not been assigned a thickness since no heat is conducted through it.

The heater head has been sized to have a heat flux consistent with the Solar Dynamic Space Experiment (SDSE) Stirling engine (reference 1). Determination of the SDSE heat flux value was not straightforward since the heater head heat flux is not one of the primary design parameters used when sizing the Stirling engine. In fact, an exact value of the heat flux into the heater head of the SDSE Stirling engine has never been

determined. Due to the complex heater head design for the SDSE engine, the actual heat flux had to be estimated. NASA LeRC engineers estimated the effective heat flux into the engine to be approximately $70,000 \text{ W/m}^2$.

Using the dimensions given for the 250 W_e GPHS/FPSE power system and assuming that all of the heat generated by the GPHS modules (1000 W_{th}) is absorbed by the heat sink, the heat flux into the heat sink is calculated to be $82,230 \text{ W/m}^2$. According to NASA LeRC, this value is acceptable for this thermal model. Using a value slightly larger than the SDSE heat flux is, in fact, preferred. As design of the GPHS/FPSE system progresses, if it is found that the FPSE cannot accommodate this heat flux, the heat flux would be reduced by increasing the heat sink surface area. This increase would result in a lower surface temperature of the GPHS modules and, therefore, a lower fuel clad temperature. Thus, the correction of any error introduced by underestimating the heat sink size could only result in lower fuel clad temperatures, which is desirable.

The heat sink surface temperature value of 1050 K also has its basis in the SDSE engine design. Although the effective hot side temperature for the SDSE engine is approximately 1030 K (reference 1), the mean heater metal temperature for the SDSE engine is slightly higher, 1080 K . Because of the simplicity of the heat sink model for the GPHS/FPSE system relative to the SDSE heater head design, it was decided that a temperature of 1050 K be used for the heat sink surface temperature.

The emissivity value of 0.8 for the cylindrical heat sink was chosen after discussion with NASA LeRC engineers. It is based upon emissivity values for materials which would be used for a Stirling engine heater head. For the disk-shaped end cap, an emissivity of 0.2 was selected. This value was based on emissivities of polished metallic surfaces at temperatures expected for this surface.

The parameters of the heat sink and the disk end cap are summarized in Table 6.2.

Table 6.2 Heat Sink and End Cap Parameters

	Heat Sink	End Cap
Dimensions	Radius: 1.0 inch Length: 3.0 inches	Radius: 1.0 inch
Heat Flux	82,230 W/m ²	N/A
Temperature	1050 K	To be determined
Emissivity	0.8	0.2

6.2.1.3 Thermal Connections

The heat sink is thermally insulated from both the end of the enclosure through which it penetrates and the disk-shaped end cap. Therefore, the heat sink and the end cap

exchange thermal energy with other nodes in the power system by radiative heat transfer only. The radiation conductor conductance values for the heat sink and end cap are generated by the TRASYS code and are included as part of the SINDA input deck in Appendix D.

6.2.2 GPHS Modules

6.2.2.1 Introduction

The GPHS modules were described in detail in Section 4.0. In this subsection a description is given of the nodes representing the exterior surfaces of the modules and the thermal connections of these nodes to the other surfaces within the power system. From this perspective, the GPHS modules can be viewed as blocked-shaped heat sources with generated heat radiating from all six external surfaces.

The thermal model representing the interior of the GPHS modules was produced specifically for this project by the Engineering Directorate of NASA Lewis Research Center (NASA LeRC). A description of the internal nodes of the GPHS thermal model and the SINDA input deck for the model can be found in Appendix B. The model contains 151 nodes with six nodes representing each fuel pellet and five nodes representing the clad of each fuel pellet. Nodes representing the iridium fuel clad are described in detail in Subsection 8.2.2 as part of the thermal analysis of the power system. The focus of the thermal analysis is on the steady-state temperature of the fuel clad nodes.

6.2.2.2 Nodal Descriptions

The GPHS modules are block-shaped with external dimensions of 3.668 in. X 3.826 in. X 2.090 in. The exterior of each GPHS module is represented in the thermal model by six rectangular arithmetic nodes corresponding to the six faces of each module. The modules are symmetrically positioned around the heat sink cylinder as described in Section 3.2. The nodes have an emissivity of 0.8. Measured radially from the center of the heat sink, the closest face of each block is one inch from the heat sink surface.

Table 6.3 summarizes the characteristics of the external nodes corresponding to one of the GPHS modules. These nodes exchange radiant energy with other surfaces within the power system enclosure. The node numbers corresponding to the other three GPHS modules are calculated by adding 2000, 4000, and 6000, respectively, to the nodes numbers given in Table 6.3. For example, nodes 101, 2101, 4101 and 6101 represent the largest face of each of the modules that faces the heat sink. Positioning of the surfaces within the enclosure is shown in Figure 6.2. Figure 8.2, included as part of the thermal analysis results, also depicts the positioning of the GPHS surface nodes relative to the heat sink cylinder.

6.2.2.3 Basis and Background for GPHS Thermal Model

For the 250 W_e GPHS/FPSE power system configuration, the GPHS thermal model (SINDA input deck in Appendix B) was duplicated four times and the nodes were

renumbered to correspond to the four individual modules. The positions of the blocks relative to each other and to the other components of the power system are specified in the TRASYS input file (Appendix C).

Table 6.3 GPHS Module Surface Nodes

Node Number	Node Shape	Dimensions (inches)	Emissivity	Positioning
100	Rectangle	2.09 X 3.826	0.8	faces node 10600
101	Rectangle	3.668 X 3.826	0.8	faces heat sink
102	Rectangle	2.09 X 3.668	0.8	side facing GPHS module
103	Rectangle	3.668 X 3.826	0.8	faces node 10400
104	Rectangle	2.09 X 3.668	0.8	side facing GPHS module
105	Rectangle	2.09 X 3.826	0.8	faces node 10500

Due to the method used in TRASYS to generate the model of the GPHS blocks, the external surfaces of the blocks had to be assigned a constant emissivity. As indicated in Tables A.6 and A.7 of Appendix A, the emissivity of the aeroshell material is actually both temperature dependant and anisotropic. Since these properties were not

incorporated into the TRASYS input, an appropriate average value for the emissivity had to be selected. The value was selected based upon the results from a NASA LeRC thermal analysis in which an individual GPHS module was analyzed in a vacuum environment, radiating to an external heat sink at a temperature of 1010° C (1850° F, 1283 K). In this environment, the GPHS surface temperatures were found to be approximately 1900° F (~1310 K). From Tables A.6 and A.7 of Appendix A, at 1900° F, an emissivity of 0.8 is a good approximation for a constant average emissivity value.

As stated in the introduction to this subsection, the thermal model representing the interior of the GPHS blocks was prepared as a precursor to this project. General Electric (GE) Company's Astro Space Division supplied values for the physical and thermal properties of the GPHS materials (Appendix A). GE has their own thermal model for the GPHS modules, but it was not available for use on this project. However, results from a thermal analysis using the GE model were available. These results were used to verify the accuracy of the model created at NASA LeRC.

As mentioned in Section 3.2, the GPHS modules are assumed to be suspended in the vacuum space in the power system enclosure. This assumption is conservative since any structure added to secure the blocks in place would provide a heat removal path superior to the exclusively radiative heat removal modeled in the analyzed configuration. Although this improved heat transfer path from the GPHS surfaces to the power system structure may degrade the overall system performance, its effect on the fuel clad temperature

would be favorable. The fuel clad temperatures would be lower than indicated by the thermal analysis performed with the current thermal model.

6.2.2.4 Thermal Connections

In the thermal model, the external surfaces of the GPHS modules do not physically contact any other nodes in the power system enclosure. Thus, the exterior nodes of the modules are connected to each other and to the other surfaces in the power system enclosure with radiation conductors. The GPHS module radiation conductor conductance values are generated by the TRASYS code and are included as part of the SINDA input deck in Appendix D. The conductance values for the GPHS module interior nodes are included in both the GPHS Thermal Model (Appendix B) and the SINDA input deck (Appendix D).

6.2.3 Power System Enclosure

6.2.3.1 Nodal Descriptions

The power system enclosure is cylindrical with an internal radius of 4.8 inches, an internal length of 4.668 inches, an external radius of 5.5 inches, and an external length of 6.068 inches. The enclosure is represented by six arithmetic nodes; two of the nodes are cylindrical and four are disk-shaped nodes. Three of the nodes represent the inner surfaces of the enclosure and the other three represent the exterior of the power system which radiates directly to space. All nodes have been given emissivity values of 0.1. The

enclosure has a thickness of 0.7 inches. The power system enclosure nodal characteristics are summarized in Table 6.4.

Table 6.4 Power System Enclosure Nodes

Node Number	Location	Node Shape	Dimensions (inches)	Emissivity
10400	Interior	Cylinder	Radius: 4.8 Length: 4.668	0.1
10600	Interior	Disk	Radius: 4.8	0.1
10500	Interior	Disk with hole	Inner Rad: 1.0 Outer Rad: 4.8	0.1
10700	Exterior	Cylinder	Radius: 5.5 Length: 6.068	0.1
10900	Exterior	Disk	Radius: 5.5	0.1
10800	Exterior	Disk with hole	Inner Rad: 1.0 Outer Rad: 5.5	0.1

6.2.3.2 Basis for Power System Enclosure Parameters

The power system enclosure was originally to be modeled with nodes and thermal conductor conductance values representative of specific physical and thermal properties of a selected multifoil insulation and an outer structural material. As work on this project continued, and a suitable insulation material had not been chosen, the decision was made

jointly by the University of Florida and NASA LeRC to model the system with negligible heat loss through the enclosure, thus eliminating the need for selection of a specific insulation material. All of the thermal energy generated by the GPHS modules is assumed to enter the internal heat sink.

Using this assumption in the thermal analysis results in higher temperatures within the power system than if the model allowed for heat loss to space through the enclosure. The assumption is conservative since the project objective is to demonstrate fuel clad temperatures below a maximum temperature value. Any direct heat loss from the actual system will be detrimental only to the overall system performance and will not jeopardize the safe operation of the GPHS modules.

The interior dimensions of the power system enclosure have been chosen to ensure adequate space for GPHS module structural supports to be added later in the system design. At the same time, the overall system volume has been minimized to ensure the lowest possible specific mass (kg/kW_e) of the system.

The exterior dimensions of the power system were selected rather arbitrarily. An enclosure thickness of 0.7 inches was chosen only because this is the thickness of the multifoil insulation for the GPHS-RTG. The actual thickness of the enclosure does not impact the thermal analysis of the GPHS/FPSE system since there is negligible heat transfer from the interior to the exterior of the enclosure.

Since the system is modeled with no heat transfer through the power system enclosure, all thermal energy is retained within the enclosure and the emissivity values of the six enclosure nodes do not affect the results of the thermal analysis. The emissivity values are specified for computational purposes only.

An emissivity value of 0.1 was chosen for the interior and exterior surfaces of the enclosure to accommodate future thermal analyses in which a specific insulation material's properties and structural material's properties are included in the thermal model and analysis. The low emissivity value for the interior surfaces will ensure maximum reflection of thermal energy within the enclosure. A low emissivity value for the external nodes will ensure the minimum radiant heat loss from the exterior of the enclosure. Surface coatings can be used to achieve low emissivity values for all of the surfaces.

6.2.3.3 Thermal Connections

The interior nodes of the power system enclosure exchange thermal energy with each other and with other nodes within the enclosure by radiative heat transfer only. None of the other nodes within the enclosure are in direct physical contact with the enclosure's inner surface. As mentioned in Subsection 6.2.1.3, the heat sink is assumed to be thermally insulated from the enclosure. The radiation conductor conductance values for the thermal connections within the enclosure are generated by the TRASYS code and are included as part of the SINDA input deck in Appendix D.

As mentioned in the previous subsection, the thermal model does not allow for direct heat loss from the enclosure to space. The radiation conductors representing the heat flow paths from the inner enclosure surface nodes to the corresponding exterior nodes have been given thermal conductance values of 1×10^{-25} Btu/hr-ft²-°F. Use of this value essentially eliminates any heat loss through the enclosure.

Since there is essentially no thermal conductance assumed in the enclosure itself, conduction conductors were not computed for heat transfer between the cylindrical nodes and the nodes representing the ends of the enclosure.

6.3 References

1. Schreiber, J., et al., "SDSE Summary," NASA Lewis Research Center, Cleveland, Ohio, Summer, 1989.
2. Conversations with Jeff Schreiber of NASA Lewis Research Center, February, 1990.

7.0 THERMAL MODEL OF THE 500 W_e GPHS/FPSE POWER SYSTEM

7.1 Introduction

As indicated in the description of the 500 W_e power system given in Section 3.3, besides the increase in overall size, there are only two primary differences between this system and the 250 W_e power system: 1) The 500 W_e power system has an additional cylindrical heat sink, and 2) it contains twice as many GPHS modules as the 250 W_e system. Because of the similarities between the thermal models of the two power systems, the following description of the 500 W_e power system thermal model details only the significant alterations made to the 250 W_e model to accommodate the higher power level.

Figure 7.1 depicts half of the power system configuration including the components and their dimensions. The nodes of interest in the thermal analysis are identified in Figure 7.2. The dimensions and physical properties associated with these nodes are given in Table 7.1 for the heat sink cylinder nodes, Table 7.3 for the exterior GPHS module nodes, and Table 7.4 for the power system enclosure nodes. Nodes representing the fuel clad in the GPHS modules are described as part of the thermal analysis in Section 9.0 of this report. Additional nodal descriptions representing the interior of the GPHS modules are given in Appendix B.

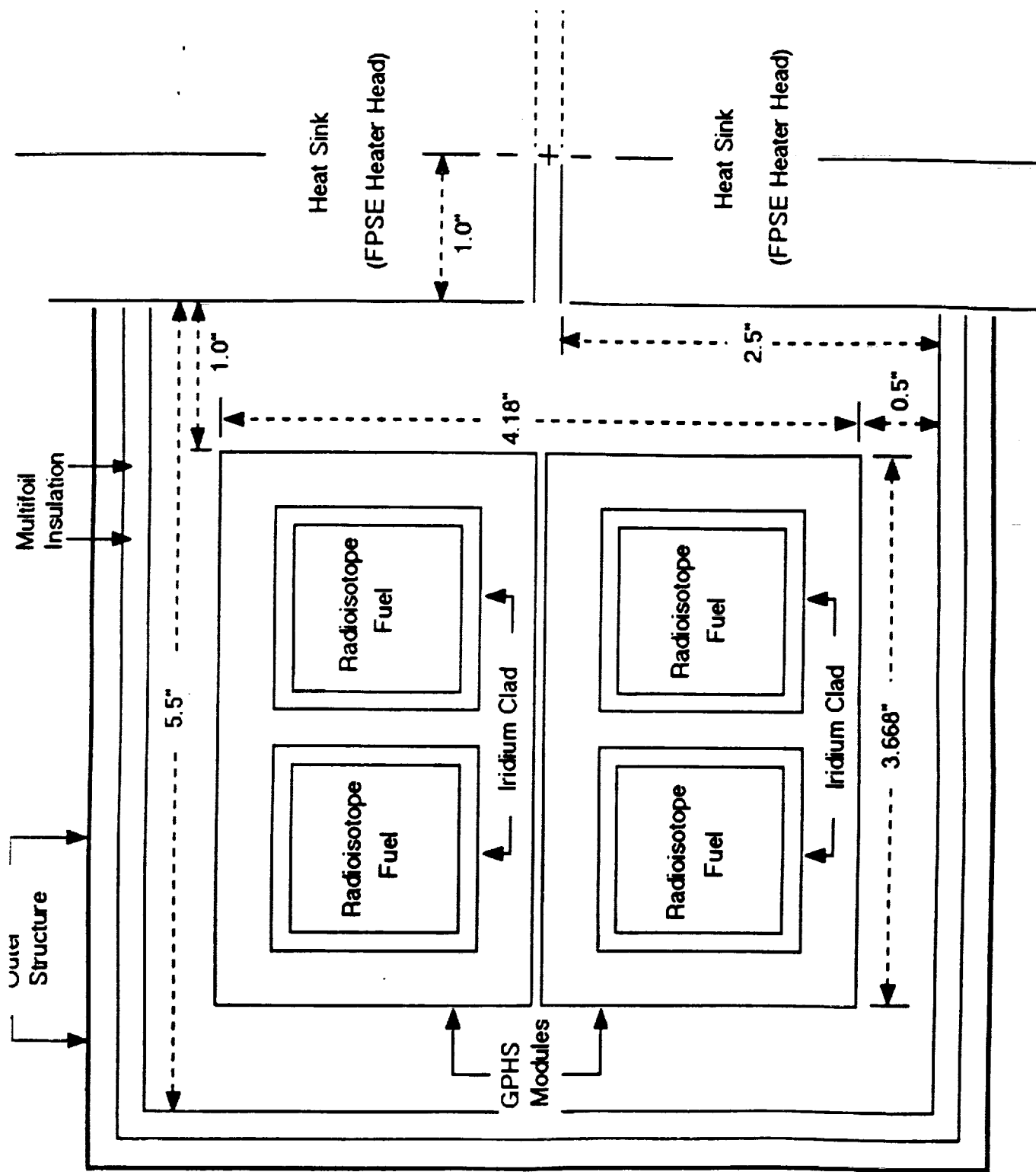


Figure 7.1 500 W(e) GPHS /FPSE Power System Configuration

7.2 Thermal Modeling of the Components

7.2.1 Heat Sinks

7.2.1.1 Nodal Descriptions

The heat sinks are situated at the center of both ends of the power system. They are each represented by single cylindrical boundary nodes with diameters of 2.0 inches, lengths of 2.5 inches, constant surface temperatures of 1050 K, and emissivities of 0.8.

At the end of each heat sink cylinder is a single arithmetic node (zero thermal capacitance) with a disk shape. The end caps have diameters of 2.0 inches and emissivities of 0.2. As in the 250 W_e system thermal model, the end caps have not been assigned thicknesses and they are thermally insulated from the heat sinks. The nodal characteristics of the heat sink cylinders and the end caps are summarized in Table 7.1.

Table 7.1 Heat Sink and End Cap Nodes

Node Numbers	Node Type	Node Shape	Dimensions (inches)	Emissivity
10100 11100	Boundary	Cylinder	Radius: 1.0 Length: 2.5	0.8
10200 11200	Arithmetic	Disk	Radius: 1.0	0.2

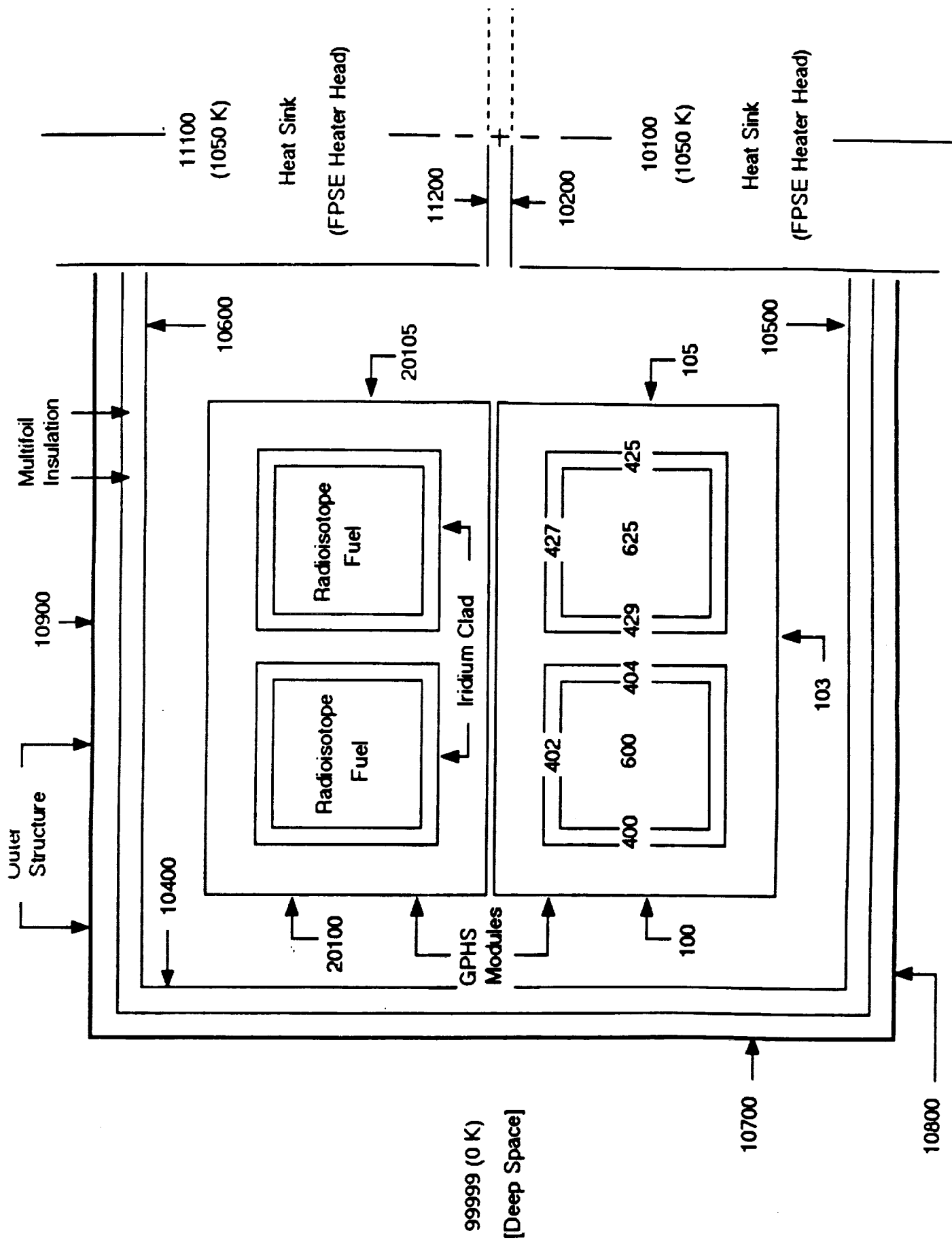


Figure 7.2 500 W(e) GP/FPSE Power System Nodal Arrangement

7.2.1.2 Basis For Heat Sink Parameters

The bases for selecting the heat sink parameters for the 500 W_e power system are identical to those used for the 250 W_e power system (See Subsection 6.2.1.2). However, in an effort to minimize the overall enclosure size, the lengths of the heat sink cylinders were reduced from 3.0 inches (250 W_e model) to 2.5 inches for the 500 W_e thermal model. This decrease in heat sink surface area results in an increase in the heater head heat flux from 82,230 W/m^2 to 98,676 W/m^2 . The increased heat flux was reviewed and approved by NASA LeRC engineers for use in this thermal analysis. Parameters for the heat sinks and the disk end caps are summarized in Table 7.2.

Table 7.2 Heat Sink and End Cap Parameters

	Heat Sinks	End Caps
Dimensions	Radius: 1.0 inch Length: 2.5 inches	Radius: 1.0 inch
Heat Flux	98,676 W/m^2	N/A
Temperature	1050 K	To be determined
Emissivity	0.8	0.2

For the purpose of this thermal analysis, the increased heat flux (smaller heat sink) is a step in the more conservative direction. If thermal analysis of the present thermal model

yields fuel clad temperatures which are too high, the model can be revised to increase the overall heat sink size. Thermal analysis using the larger heat sink surface area (lower heater head heat flux) would result in lower fuel clad temperatures.

7.2.1.3 Thermal Connections

As in the 250 W_e thermal model, the heat sinks are thermally insulated from the ends of the enclosure through which they penetrate and from the disk-shaped end caps. Therefore, the heat sinks and the end caps exchange thermal energy with other nodes in the power system by radiative heat transfer only. The heat sink and end cap radiation conductor conductance values are generated by the TRASYS code and are included as part of the SINDA input deck.

7.2.2 GPHS Modules

7.2.2.1 Nodal Descriptions

As in the 250 W_e power system thermal model, the exterior of each GPHS module is represented in the thermal model by six arithmetic nodes corresponding to the six faces of each module. All of the GPHS surface nodes have emissivities of 0.8. Measured radially from the center of the heat sink, the closest face of each set is one inch from the heat sink surface.

As described in Section 3.3, the eight GPHS modules are stacked symmetrically around

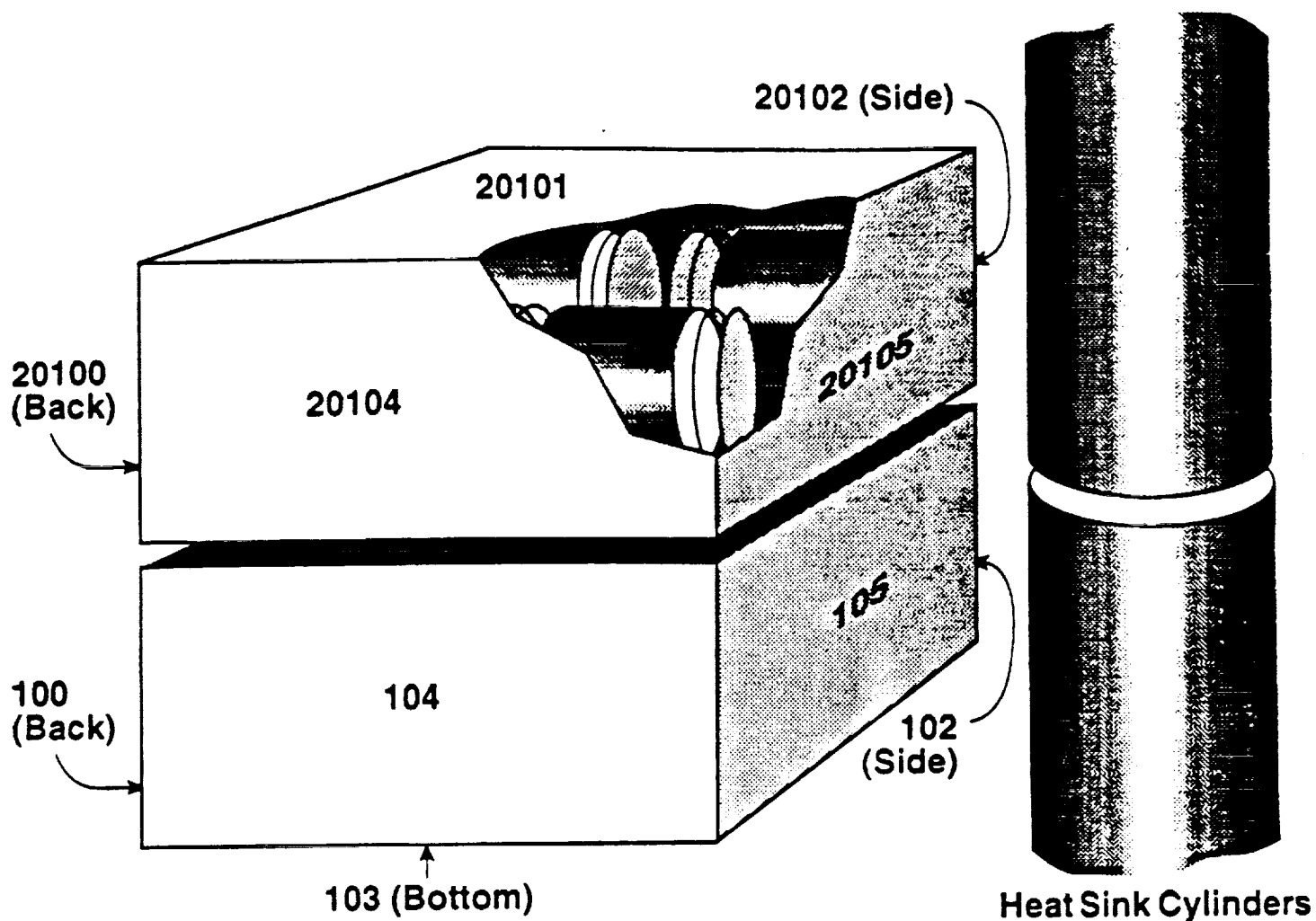
the heat sinks in four sets of two. The thermal model representing each set consists of two complete models of a GPHS module. The external nodes of the GPHS modules in one set are shown in Figure 7.3. The characteristics of the external nodes are summarized in Table 7.3. The node numbers corresponding to the three other sets of GPHS modules are calculated by adding 2000, 4000, and 6000, respectively, to the nodes numbers given in Table 7.3.

The interior of each GPHS module is represented in the thermal model by the same model that was used for the GPHS modules in the 250 W_e system thermal model (See Subsection 6.2.2 and Appendix B).

7.2.2.2 Basis and Background for GPHS Thermal Model

For the configuration of the 500 W_e GPHS/FPSE power system, the GPHS thermal model (Appendix B) was duplicated eight times and the nodes were renumbered to correspond to the eight individual modules. The positions of the blocks relative to each other and to the other components of the power system are specified in the TRASYS input file.

The bases used for selecting the physical parameters of the GPHS modules and their positioning within the power system are the same as those used for the 250 W_e power system thermal model (See Subsection 6.2.2.2).



Not shown:

101 - top face of bottom module

20103 - bottom face of top module

Figure 7.3 GPHS Exterior Nodal Configuration for the 500 W. Power System

Table 7.3 GPHS Module Surface Nodes

Node Number	Node Shape	Dimensions (inches)	Emissivity	Positioning
100	Rectangle	2.09 X 3.826	0.8	Faces node 10400
101	Rectangle	3.668 X 3.826	0.8	In contact with node 20103
102	Rectangle	2.09 X 3.668	0.8	Side facing GPHS module
103	Rectangle	3.668 X 3.826	0.8	Faces node 10500
104	Rectangle	2.09 X 3.668	0.8	Side facing GPHS module
105	Rectangle	2.09 X 3.826	0.8	Faces heat sink
20100	Rectangle	2.09 X 3.826	0.8	Faces node 10400
20101	Rectangle	3.668 X 3.826	0.8	Faces node 10600
20102	Rectangle	2.09 X 3.668	0.8	Side facing GPHS module
20103	Rectangle	3.668 X 3.826	0.8	In contact with node 101
20104	Rectangle	2.09 X 3.668	0.8	Side facing GPHS module
20105	Rectangle	2.09 X 3.826	0.8	Faces heat sink

7.2.2.3 Thermal Connections

In the 500 W_e system thermal model, the external surfaces of each set of GPHS modules do not physically contact any other nodes in the power system enclosure. However, since there are two modules per set, there are two GPHS surface nodes in each set that are in contact with each other. In the thermal model, these surfaces are connected by radiation conductors. In order to connect the surfaces radiatively, the thermal model had to include a small gap between the surfaces. The gap is only 0.006 inches; therefore, the surfaces exchange thermal energy only with each other.

As in the 250 W_e system thermal model, all other exterior nodes of the GPHS modules are connected to each other and to the other surfaces in the power system enclosure with radiation conductors. The radiation conductor conductance values connecting the GPHS module exterior surface nodes to the other surface nodes in the power system are generated by the TRASYS code and are included as part of the SINDA input deck.

7.2.3 Power System Enclosure

7.2.3.1 Nodal Descriptions

Similar to the 250 W_e system thermal model, the 500 W_e power system enclosure is represented by six arithmetic nodes. Two of the nodes are cylindrical and four are disk-shaped nodes. Three of the nodes represent the inner surfaces of the enclosure and the

other three represent the exterior of the power system which radiates directly to space. All nodes have been assigned emissivity values of 0.1. The enclosure has a thickness of 0.7 inches.

There are only two differences between the power system enclosure nodes in the 500 W_e system thermal model and the 250 W_e system thermal model. The most significant difference is that instead of having a smooth disk-shaped node at one end of the enclosure as in the 250 W_e system model, both ends of the 500 W_e system enclosure have disk-shaped nodes with holes in the center to accommodate the additional heat sink. The other difference is, of course, the size of the nodes, which are larger due to the increased enclosure volume required to house the eight GPHS modules. The power system enclosure nodal characteristics are summarized in Table 7.2.

It is interesting to note that, even with the reduced heat sink size for the 500 W_e power system, the internal volume of the enclosure is still more than double the volume of the 250 W_e system; 687.6 in³ for the 500 W_e system and 337.9 in³ for the 250 W_e system.

7.2.3.2 Basis for Power System Enclosure Parameters

The bases for selecting the nodal representation of the power system enclosure are identical to those used for the 250 W_e system thermal model. And, as in the 250 W_e system model, the 500 W_e power system is modeled with no heat loss through the enclosure to space.

Table 7.4 Power System Enclosure Nodes

Node Number	Location	Node Shape	Dimensions (inches)	Emissivity
10400	Interior	Cylinder	Radius: 6.5 Length: 5.18	0.1
10600	Interior	Disk with hole	Inner Rad: 1.0 Outer Rad: 6.5	0.1
10500	Interior	Disk with hole	Inner Rad: 1.0 Outer Rad: 6.5	0.1
10700	Exterior	Cylinder	Radius: 7.2 Length: 6.58	0.1
10900	Exterior	Disk with hole	Inner Rad: 1.0 Outer Rad: 7.2	0.1
10800	Exterior	Disk with hole	Inner Rad: 1.0 Outer Rad: 7.2	0.1

7.2.3.3 Thermal Connections

As in the 250 W_e system thermal model, the interior nodes of the power system enclosure exchange thermal energy with each other and with other nodes within the enclosure by radiative heat transfer only. None of the other nodes within the enclosure are in direct physical contact with the enclosure's inner surface. The radiation conductor conductance values for the thermal connections within the enclosure are generated by

the TRASYS code and are included as part of the SINDA input deck.

As mentioned in the previous subsection, the thermal model does not allow for direct heat loss from the enclosure to space. The radiation conductor conductance values representing the heat flow paths from the inner surface nodes to the corresponding exterior nodes are the same as those used in the 250 W_e system thermal model, 1×10^{-25} Btu/hr·ft·°F. Use of this value essentially eliminates any heat loss through the enclosure.

As in the 250 W_e system thermal model, since there is essentially no thermal conductance assumed in the enclosure itself, conduction conductors were not computed for heat transfer between the cylindrical nodes and the nodes representing the ends of the enclosure.

8.0 THERMAL ANALYSIS OF THE 250 W_e GPHS/FPSE POWER SYSTEM

8.1 Description of Analysis

8.1.1 Introduction

The thermal analysis of the 250 W_e GPHS/FPSE power system is performed using the thermal model described in Section 6.0. The code, TRASYS, is used to generate conductance values for the radiation conductors which connect the surface nodes within the power system enclosure. The code, SINDA, is used to generate the steady-state temperature distribution throughout the entire thermal system.

8.1.2 TRASYS Analysis

The surface nodes are defined in the TRASYS input file (Appendix C). Dimensions are specified for the heat sink and end cap nodes, the exterior nodes of the GPHS modules and the nodes representing the inner surfaces of the power system enclosure. The positions of the components with relation to one another are also specified. The interior of the power system enclosure contains 29 surface nodes (24 faces of the GPHS modules, 3 power system enclosure surfaces, the heat sink cylinder and the heat sink end cap). Emissivity values for each node are specified.

Application of the TRASYS code to the 250 W_e GPHS/FPSE power system thermal model

yields 406 radiation conductors connecting the surface nodes within the power system enclosure. The conductors are numbered 1 through 406 and are included as part of the SINDA input deck in Appendix D. For each radiation conductor number, the nodes which are connected are identified and the conductance value for the conductor is generated.

8.1.3 SINDA Analysis

The SINDA code is a thermal analyzer that utilizes resistor-capacitor (R-C) network representations of thermal systems. SINDA is used to generate the steady-state temperature within the GPHS modules and throughout the power system enclosure.

The bulk of the SINDA input deck is dedicated to defining the nodes and conductors in the thermal model. The radiation conductors and the corresponding conductance values which are generated by the TRASYS code are inserted directly into the conductor segment of the SINDA input deck. The remainder of the input deck is used to define the heat generation rates in the fuel pellet nodes and to specify the SINDA subroutines to be executed.

Three SINDA subroutines are used for the thermal analysis; STDSTL, TPRINT, and QIPRNT. STDSTL is a thermal network solution subroutine which calculates the finite difference steady-state solution. TPRINT is a printout subroutine which produces a printout of all the nodal temperatures in the steady-state solution. QIPRNT is also a printout subroutine; it produces a printout of the heat generation rate for each node in

the thermal system. QIPRNT is used to verify the heat generation rates for the fuel pellet nodes and to verify that all other nodes have a heat generation rate of zero.

8.1.4 Initial Temperatures

All nodes in the thermal model of the 250 W_e GPHS/FPSE power system are given an initial temperature as a starting point for the iterative process used for the thermal analysis by the SINDA code. The boundary node temperatures and the initial temperatures for the arithmetic nodes are listed in Table 8.1.

Table 8.1 Initial Nodal Temperatures for Thermal Analysis
of the 250 W_e GPHS/FPSE Power System

Node Numbers	Node Description	Node Type	Initial Temperature
10100	Heat Sink	Boundary	1430° F
99999	Deep Space	Boundary	-460° F
10200	Heat Sink End Cap	Arithmetic	1500° F
10400 10500 10600	Inner Surfaces of Power System Enclosure	Arithmetic	1500° F
10700 10800 10900	Outer Surfaces of Power System Enclosure	Arithmetic	200° F
	ALL Other Nodes	Arithmetic	2000° F

8.2 Results And Interpretations of Thermal Analysis

8.2.1 Introduction

The SINDA output file contains the steady-state temperature for each of the 609 nodes in the thermal model. For the purpose of this analysis, only the temperatures of selected nodes throughout the power system are presented.

8.2.2 Fuel Clad Temperatures

Examination of the fuel clad nodal temperatures is most important since the primary design objective is to demonstrate temperatures of the fuel clad below the design goal temperature limit of 1573 K under normal operating conditions. With 5 nodes representing the fuel clad of each fuel pellet, there are 80 fuel clad nodes in the thermal system.

Evaluation of the thermal analysis results is simplified considerably due to the symmetry of the system. From the top view of the power system shown in Figure 8.1, it can be seen that, since the thermal model representing each GPHS model is identical, analogous nodes in each of the modules should have similar temperatures when the system is in thermal equilibrium. In addition, analogous nodes on either side of each module should have similar temperatures. Accuracy of the analysis is verified by examining temperatures of the analogous nodes within the GPHS modules.

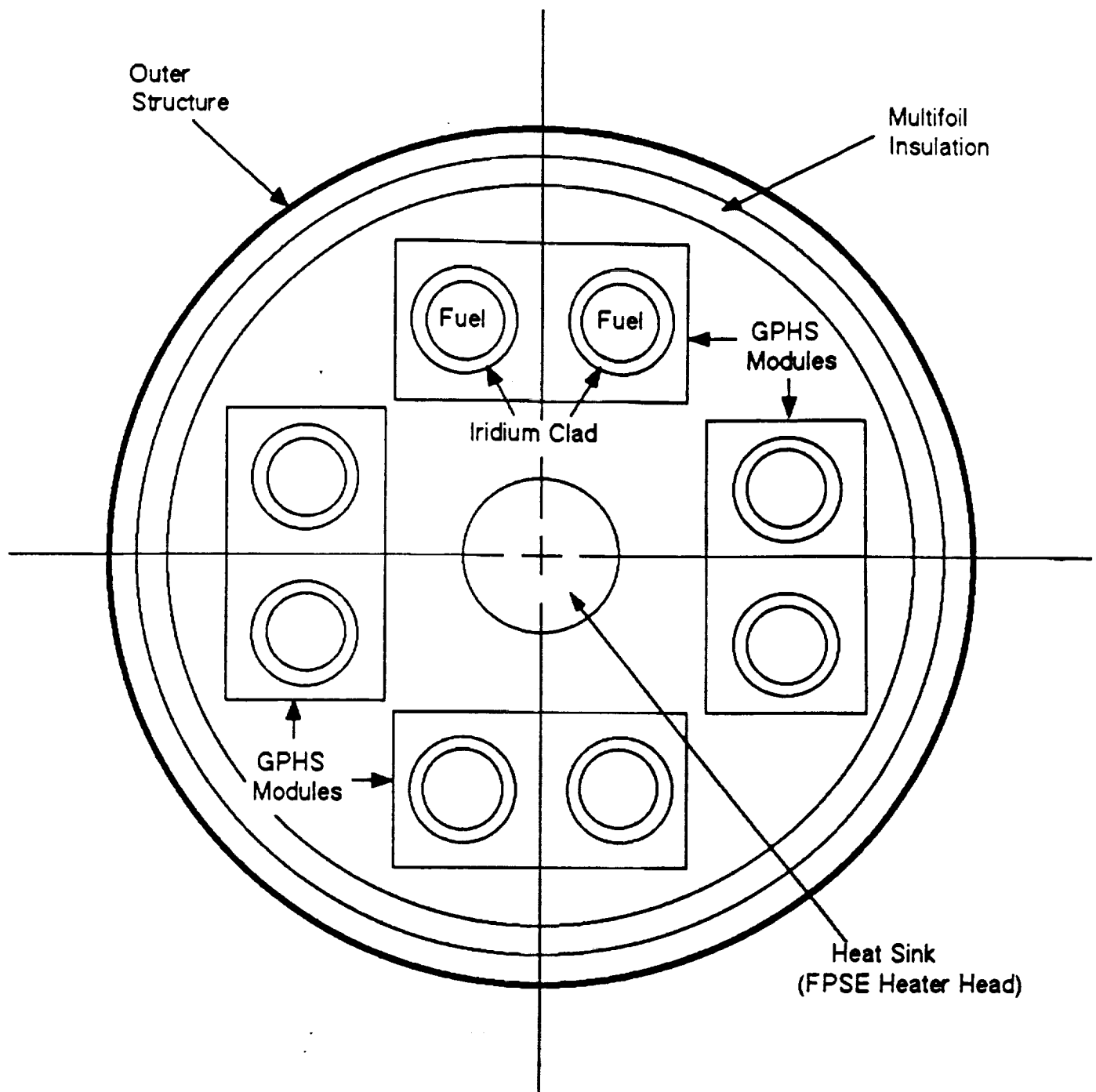


Figure 8.1 Symmetry of 250 W(e) Power System From Top View

Before examining the temperatures of the analogous nodes, it is necessary to present a brief description of the nodes representing the fuel clad of each pellet. The nodes numbered 400 to 429 and 1400 to 1429 are identified in Figure 8.2. Analogous nodes in each of the other four modules are calculated by adding 2000, 4000, and 6000, respectively, to the node numbers shown in Figure 8.2. For example, nodes 427, 2427, 4427, and 6427 represent the cylindrical portion of the fuel clad for a fuel pellet in the identical quadrant of a GPHS module. Physical descriptions for the fuel clad nodes shown in Figure 8.2 are given in Table 8.2. The positioning of the GPHS modules within the power system was shown in Figure 6.2.

Table 8.2 Description of Fuel Clad Nodes

Node Numbers	Description of Nodes
400, 425, 404, 429 1400, 1425, 1404, 1429	Disk-shaped nodes which represent the ends of the fuel clad cylinders.
401, 403 426, 428 1401, 1403, 1426, 1428	Ring-shaped nodes which connect the disk-shaped end nodes to the cylindrical nodes.
402, 427, 1402, 1427	Cylindrical nodes which represent the cylindrical portions of the fuel clad.

A comparison of analogous nodal temperatures is contained in Tables 8.3 and 8.4; Table

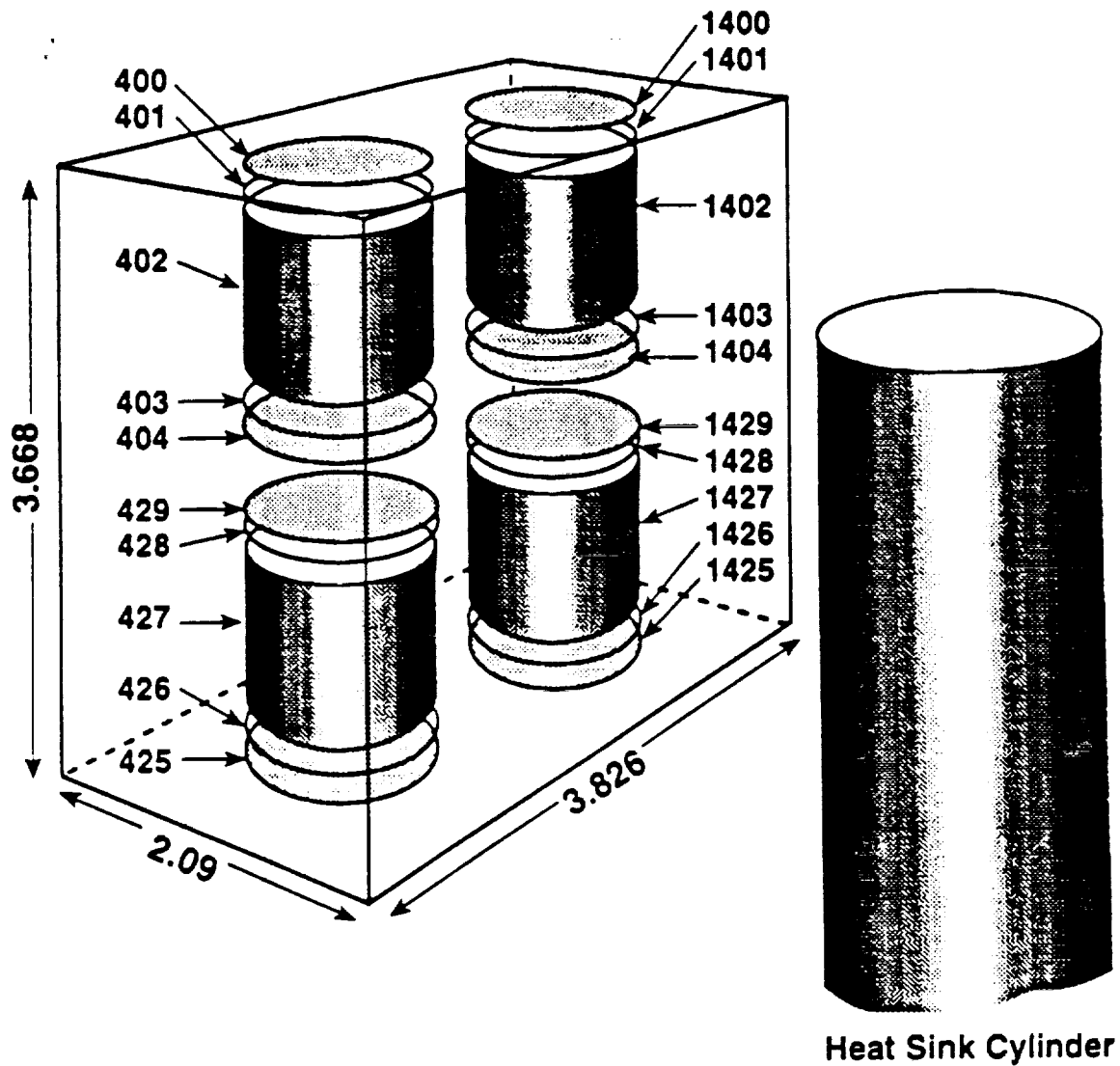


Figure 8.2 Iridium Fuel Clad Nodal Arrangement

8.3 compares the steady-state temperatures for a selection of analogous fuel clad nodes in each of the four GPHS modules and Table 8.4 compares the temperatures for analogous nodes within one GPHS module.

Table 8.3 Comparison of Temperatures For Analogous Fuel Clad Nodes in Different GPHS Modules

Node Number	GPHS Block	Temperature °F (K)
400	1	2406 (1592)
2400	2	2405 (1592)
4400	3	2405 (1592)
6400	4	2406 (1592)
404	1	2454 (1618)
2404	2	2453 (1618)
4404	3	2453 (1618)
6404	4	2454 (1618)
427	1	2456 (1620)
2427	2	2456 (1620)
4427	3	2456 (1620)
6427	4	2456 (1620)

As indicated in Tables 8.3 and 8.4, the thermal analysis has demonstrated nearly identical temperatures for the analogous fuel clad nodes in each of the GPHS modules and on either side of each module. Therefore, the number of nodal temperatures examined can be reduced to the ten nodes representing the fuel clad of two of the fuel pellets in one GPHS module.

Table 8.4 Comparison of Temperatures for Analogous Fuel Clad Nodes in One GPHS Module

Node Number	Temperature °F (K)
401	2447 (1615)
1401	2447 (1615)
403	2456 (1620)
1403	2456 (1620)
425	2404 (1591)
1425	2404 (1591)
429	2453 (1618)
1429	2453 (1618)

The fuel clad nodal temperatures determined by the thermal analysis for the ten nodes representing the fuel clad of two of the fuel pellets in one GPHS module are listed in Table 8.5 and shown in Figure 8.3.

As indicated in the Figure 8.3 and Table 8.5, the temperatures of the fuel clad nodes are slightly higher than the design goal temperature limit of 1573 K. After discussion with NASA LeRC engineers, it was decided that the temperatures shown by the thermal analysis are sufficiently close to the design temperature limit to warrant further investigation of the power system. This decision was based on the close proximity of the fuel clad temperatures to the temperature limit, the ambiguous nature of the limit itself,

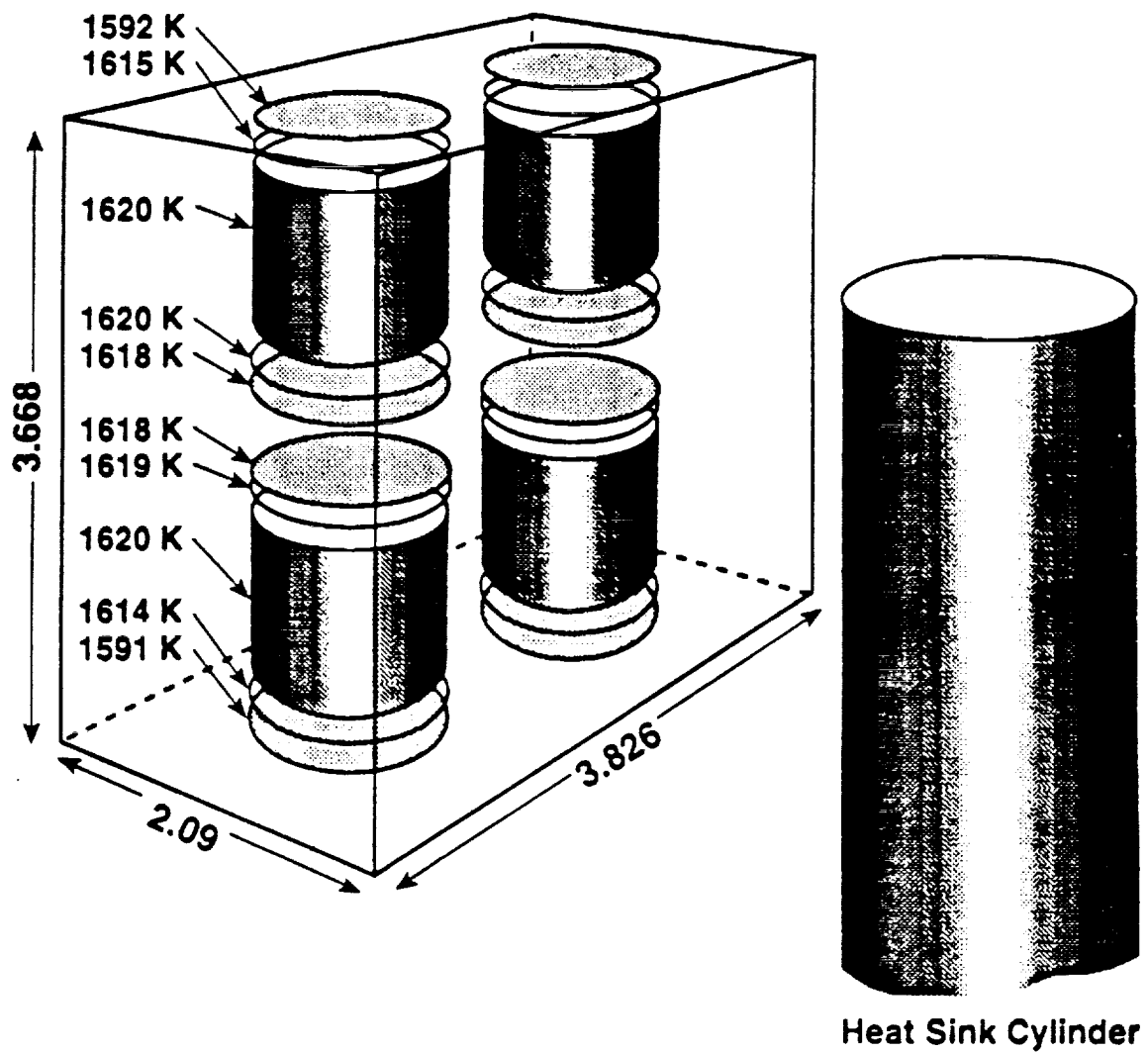


Figure 8.3 Iridium Fuel Clad Nodal Temperatures

and the conservative assumptions incorporated into the thermal model and used in the thermal analysis.

Table 8.5 250 W_e GPHS/FPSE Power System Fuel Clad Nodal Temperatures

Node Number	Temperature °F (K)		Node Number	Temperature °F (K)
400	2406 (1592)		425	2404 (1591)
401	2447 (1615)		426	2446 (1614)
402	2456 (1620)		427	2456 (1620)
403	2456 (1620)		428	2455 (1619)
404	2454 (1618)		429	2453 (1618)

As a more detailed design of the GPHS/FPSE system is established, the thermal model can be modified to remove some of the conservatism of the thermal analysis. Once an insulation material is selected, the nature of the heat sink is determined, and structural supports for the GPHS modules are added, a thermal analysis of the detailed system design should yield lower fuel clad temperatures.

8.2.3 Temperatures Throughout the Power System Enclosure

Temperatures generated for nodes representing other surfaces of the power system are shown in Figure 8.4. The components and node numbers corresponding to the indicated

[Deep Space]
(0 K)

Multifoil
Insulation

Outer
Structure

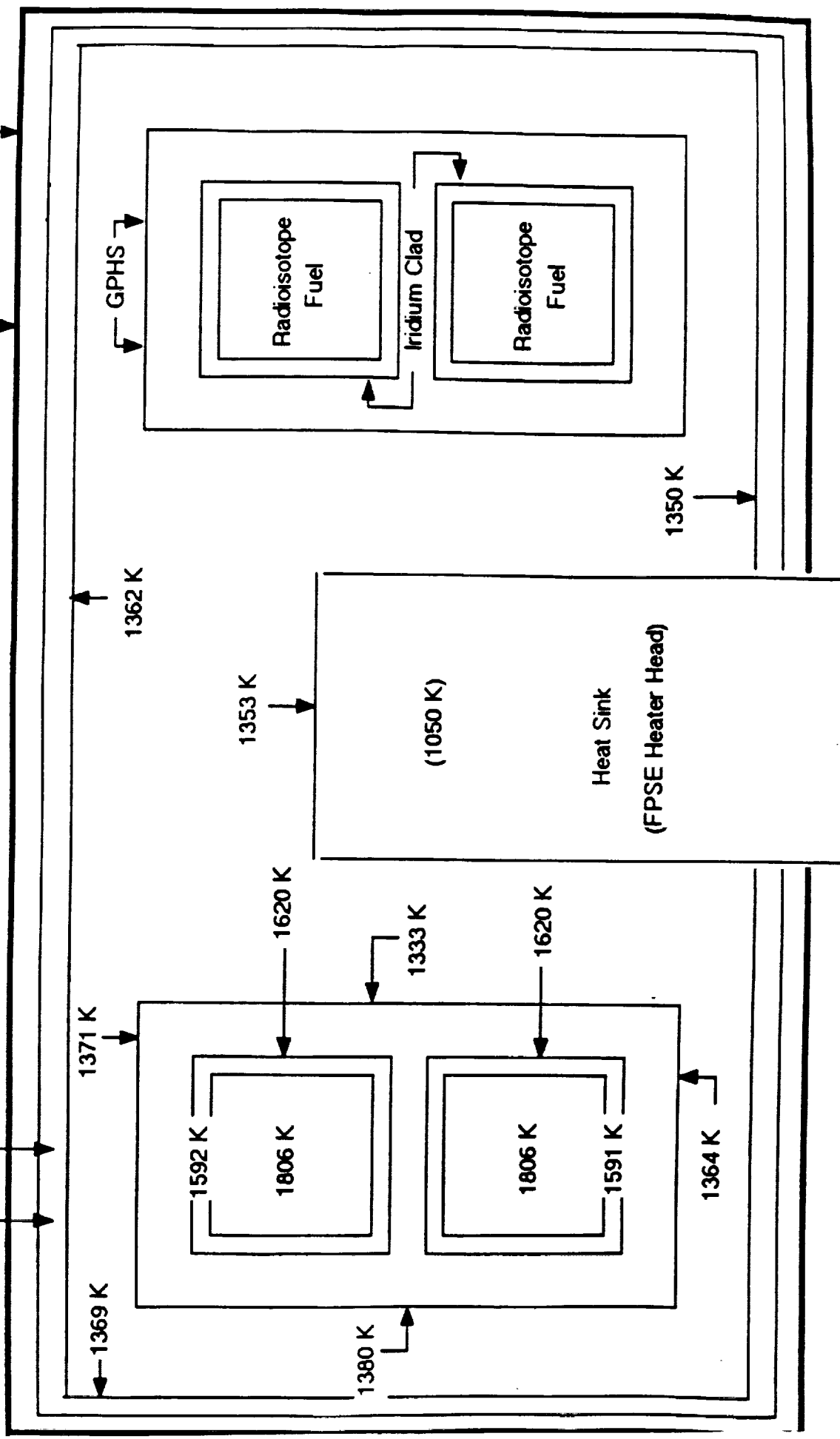


Figure 8.4 Nodal Temperatures Throughout the 250 W(e) GPHS/FPSE Power System

temperatures were shown in Figures 6.1 and 6.2. Temperatures throughout the power system are certainly within acceptable ranges for materials considered for use in the power system.

An interesting observation is made concerning the temperatures of the nodes representing the power system enclosure inner surfaces. One would expect the inner surface temperature of the enclosure to lie somewhere between the heat source (GPHS modules' surfaces) temperatures (1333 K - 1380 K) and the temperature of the heat sink (1050 K). The thermal analysis has computed inner surface nodal temperatures (1350 K - 1369 K) that lie within the heat source temperature range.

At first glance, it appears that this solution indicates an error in the thermal analysis. Upon further examination, however, this apparent discrepancy can be easily explained.

To start, all of the surfaces within the enclosure can be placed in one of three categories; (1) heat source, (2) heat sink or (3) power system enclosure inner surface (enclosure node). Since radiative heat transfer is the only mechanism by which the surfaces in each category exchange thermal energy, heat transfer between the surfaces depends upon the size, temperature and emissivity of each of the surfaces and on the geometric view factors connecting the surfaces. Ignoring the emissivities and the view factors for now, an equivalent 'surface-area-averaged' temperature for each set of surfaces (heat source, heat sink, enclosure) is calculated and compared to demonstrate that the

equivalent enclosure temperature does in fact lie between the equivalent heat source and heat sink temperatures. The surface emissivity values and the view factors connecting the surfaces are examined later since they help to determine whether the enclosure temperature is closer to the heat source temperature or the heat sink temperature.

The equivalent 'surface-area-averaged' temperatures for the heat source, heat sink and enclosure surfaces are calculated using the following equation:

$$T_{SA} = \frac{\sum A_i T_i}{\sum A_i}$$

where: T_{SA} = 'Surface-Area-Averaged' Temperature

A_i = Area of Surface i

T_i = Temperature of Surface i

The calculated 'surface-area-averaged' temperatures along with the total surface area for each element of the system are given in Table 8.6. From these temperatures, it is shown that the 'surface-area-averaged' temperature of the enclosure's inner surface is slightly lower than the heat source 'surface-area-averaged' temperature. The close proximity of the enclosure temperature to the heat source temperature can be explained by examining the heat transfer paths connecting the surfaces and the significant

difference in surface area between the surfaces supplying heat to the system and the one surface removing heat from the system.

Table 8.6 'Surface-Area-Averaged' Temperatures For The Heat Source, Heat Sink, and Enclosure Surface

Surface	Total Surface Area, ΣA_i	'Surface-Area-Averaged' Temperature
Heat Source	237.6 in ²	1364.0 K
Power System Enclosure Inner Surface	282.4 in ²	1362.5 K
Heat Sink	18.9 in ²	1050.0 K

Examining the surface areas first, it is seen that the four GPHS modules have a total surface area of 237.6 in² and a 'surface-area-averaged' temperature of 1364.0 K, while the heat sink surface area is only 18.9 in² with a temperature of 1050 K. With greater than 12 times the surface area than the heat sink, and because radiative heat transfer is a function of temperature to the fourth power, the GPHS surfaces have a much greater influence on the inner surface temperature of the power system enclosure.

When looking at the heat transfer paths, it is seen that most of the heat sink surface is

blocked by the GPHS modules from direct thermal energy exchange with the enclosure surfaces. Therefore, the values for the geometric view factors which connect the enclosure nodes to the heat sink node are very low, reducing the heat sink temperature's influence on the enclosure temperature. Since both the heat source and heat sink have emissivities of 0.8, the emissivities are not a factor when comparing the relative influence of each on the enclosure temperature.

From the above discussion, it can be concluded that a calculated 'surface-area-averaged' temperature of 1362.5 K for the enclosure surfaces is not unreasonable, as it may first appear.

8.2.4 Sensitivity Analysis

As a followup to the thermal analysis results presented in the previous subsections, a brief sensitivity analysis was performed to determine the effects of varying some of the key system parameters on the fuel clad nodal temperatures. The thermal analysis performed using the thermal model described in this report used conservative values for most of the system parameters. Understanding the effects of variations in these parameters is essential prior to further development of the power system.

Five system parameters whose variance would impact the clad temperatures have been identified for the sensitivity analysis; (1) direct heat loss to space (variance of the conductance through the power system enclosure), (2) the heat sink surface area, (3)

the distance between the GPHS modules and the heat sink, (4) the emissivity of the inner surfaces of the power system enclosure, and, (5) the emissivity of the heat sink cylinder.

Three of the five key parameters were varied for this sensitivity analysis. The GPHS module positions were not varied since this requires a rather extensive revision to the current thermal model. Varying the distance between the modules and the heat sink and repositioning of the modules within the enclosure (turning them so different module surfaces face the heat sink) is recommended for future study. The emissivity values for the inner surfaces of the power system enclosure were not varied since, using the current thermal model (no heat transfer through the enclosure), the emissivity values have no effect on the thermal analysis results. Once an insulation material has been selected, this parameter should be varied to determine its effect on the fuel clad nodal temperatures.

The direct heat loss from the system to space was varied by selecting three different conductor conductance values connecting the interior nodes of the power system enclosure to the exterior nodes. The corresponding heat loss was calculated from the temperatures of the exterior nodes as predicted by the SINDA thermal analysis. The range of iridium clad temperatures for each of the three cases is shown in Table 8.7.

Table 8.7 Fuel Clad Nodal Temperatures as a Function of Heat Loss to Space

Heat Loss (W)	Iridium Clad Nodal Temperatures (K)
0.0	1591 - 1620
20.0	1588 - 1617
45.6	1584 - 1617
83.3	1578 - 1607

As shown in Table 8.7, as the heat loss through the enclosure increases, the fuel clad temperatures slowly decreases. Based upon the direct heat loss to space from the GPHS-RTG (see Reference 1), a heat loss of about 5% (50 W) could be expected for an actual GPHS/FPSE power system. From Table 8.7, a decrease in fuel clad temperature of 7 to 8 K could result from such a heat loss. However, a design which provides for increased heat loss from the system is not desirable since it will result in decreased system performance.

The heat sink size was varied directly by changing the input value in the TRASYS input file. Cylinder lengths of 2.5 and 3.5 inches were used for the analysis. The range of iridium fuel clad nodal temperatures for each heat sink size is shown in Table 8.8. The heat sink heat flux corresponding to each heat sink size is also given.

Table 8.8 Fuel Clad Nodal Temperatures as a Function of Heat Sink Size

Heat Sink Cylinder Length (in.)	Heat flux (W/m ²)	Iridium Clad Nodal Temperatures (K)
2.5	98,676	1615 - 1645
3.0	82,230	1591 - 1620
3.5	70,483	1571 - 1599

As shown in Table 8.8, increasing the heat sink cylinder length 0.5 inches results in a heat sink heat flux similar to the estimated Solar Dynamic Space Experiment (SDSE) FPSE heater head heat flux of 70,000 W/m² (see Section 6.2). The corresponding fuel clad nodal temperatures are lower and approach the design goal of 1573 K. Thus the design of the GPHS/FPSE system should strive for a heat sink heat flux value of 70,000 W/m² or below.

The heat sink emissivity value was also varied by changing the input value into the TRASYS input file. Emissivity values of 0.7 and 0.9 were used for the analysis. The range of fuel clad nodal temperatures corresponding to these emissivity values is shown in Table 8.9.

As shown in Table 8.9, a heat sink emissivity of 0.9 reduces the fuel clad nodal temperatures close to the design goal of 1573 K. Thus, a coating which could provide a heat sink emissivity greater than 0.8 is recommended for the system. A heat sink

emissivity of 0.9 in combination with a larger heat sink size could reduce all fuel clad nodal temperatures to the design goal of 1573 K.

Table 8.9 Fuel Clad Nodal Temperatures as a Function of Heat Sink Emissivity

Heat Sink Emissivity	Iridium Clad Nodal Temperatures (K)
0.7	1610 - 1639
0.8	1591 - 1620
0.9	1576 - 1604

The sensitivity analysis has shown that varying the heat sink parameters has the greatest effect on the fuel clad nodal temperatures. As design of the 250 W_e GPHS/FPSE system continues, primary emphasis must be placed on incorporating as large a heat sink as possible with the lowest heat flux achievable. Direct heat loss from the system will tend to decrease the clad temperatures, but this mechanism should not be relied upon too strongly since it will adversely affect the overall system performance.

8.3 References

1. Final Safety Analysis Report For The Galileo Mission, Prepared for the U.S. Department of Energy by General Electric's Astro-Space Division Under Contract DE-AC01-79ET32043, May, 1988.

9.0 THERMAL ANALYSIS OF THE 500 W_e GPHS/FPSE POWER SYSTEM

9.1 Description of Analysis

9.1.1 Introduction

The thermal analysis of the 500 W_e GPHS/FPSE power system is very similar to the thermal analysis of the 250 W_e power system. The analysis was performed using the thermal model described in Section 7.0. The TRASYS code is used to generate conductance values for the radiation conductors which connect the surface nodes within the power system enclosure. The SINDA code is used to generate the steady-state temperature distribution throughout the entire thermal system. Due to the similarities between the TRASYS and SINDA input files for the 250 W_e and 500 W_e power systems, and the lengths of the files, the input files for the 500 W_e system are not included as appendices.

9.1.2 TRASYS Analysis

The surfaces within the power system enclosure are defined in the TRASYS input file. Dimensions are specified for the heat sink, the GPHS modules and the inner surfaces of the power system enclosure. The positions of the components with relation to one another are also specified. The interior of the 500 W_e power system enclosure contains 55 surfaces (48 faces of the GPHS modules, 3 power system enclosure surfaces, two

heat sink cylinders and the two heat sink end caps). Emissivity values for each surface are specified.

Application of the TRASYS code to the 500 W_e GPHS/FPSE power system thermal model yields 1085 radiation conductors connecting the surfaces within the power system enclosure. The conductors are numbered 1 through 1085 and are included as part of the SINDA input deck. For each radiation conductor number, the nodes which are connected are identified and the conductance value for the conductor is generated.

9.1.3 SINDA Analysis

As in the 250 W_e SINDA input deck, the bulk input deck is dedicated to defining the nodes and conductors in the thermal model. The radiation conductors and the corresponding conductance values which are generated by the TRASYS code are inserted directly into the conductor segment of the SINDA input deck. The remainder of the input deck is used to define the heat generation rates in the fuel pellet nodes and to specify the SINDA subroutines to be executed.

The same three SINDA subroutines (STDSTL, TPRINT, and QIPRNT) used for the 250 W_e system thermal analysis are used for the 500 W_e system thermal analysis. STDSTL is a thermal network solution subroutine which calculates the finite difference steady-state solution. TPRINT is a printout subroutine which produces a printout of all the nodal temperatures in the steady-state solution. QIPRNT is also a printout subroutine; it

produces a printout of the heat generation rate for each node in the thermal system. QIPRNT is used to verify the heat generation rates for the fuel pellet nodes and to verify that all other nodes have a heat generation rate of zero.

9.1.4 Initial Temperatures

As in the 250 W_e SINDA input deck, all nodes in the thermal model of the 500 W_e GPHS/FPSE power system are given an initial temperature as a starting point for the iterative process used for the thermal analysis by the SINDA code. The boundary node temperatures and the initial temperatures for the arithmetic nodes are listed in Table 9.1.

**Table 9.1 Initial Nodal Temperatures for Thermal Analysis
of the 500 W_e GPHS/FPSE Power System**

Node Numbers	Node Description	Node Type	Initial Temperature
10100 11100	Heat Sinks	Boundary	1430° F
99999	Deep Space	Boundary	-460° F
10200 11200	Heat Sink End Caps	Arithmetic	1500° F
10400 10500 10600	Inner Surfaces of Power System Enclosure	Arithmetic	1500° F
10700 10800 10900	Outer Surfaces of Power System Enclosure	Arithmetic	200° F
	ALL Other Nodes	Arithmetic	2000° F

9.2 Results And Interpretations of Thermal Analysis

9.2.1 Introduction

The SINDA output file contains the steady-state temperature for each of the 1211 nodes in the thermal model. For the purpose of this analysis, only the temperatures of selected nodes throughout the power system are presented.

9.2.2 Fuel Clad Temperatures

As in the 250 W_e power system thermal analysis, examination of the fuel clad nodal temperatures is most important since the primary design objective is to demonstrate temperatures of the fuel clad below the design goal temperature limit of 1573 K under normal operating conditions. With 8 GPHS modules, 4 fuel pellets per modules, and 5 nodes representing the fuel clad of each fuel pellet, there are 160 fuel clad nodes in the 500 W_e power system thermal network. Again, evaluation of all the nodal temperatures is not necessary because of the symmetry in the system configuration.

Figures 9.1a and 9.1b, respectively, illustrate the symmetry of the 500 W_e from both side and top views of the power system. From the top view (Figure 9.1b), it can be seen that analogous nodes in each set of GPHS modules should have similar temperatures when the system is in thermal equilibrium. In addition, analogous nodes on either side of each set of modules should have similar temperatures. From the side view (Figure 9.1a), it

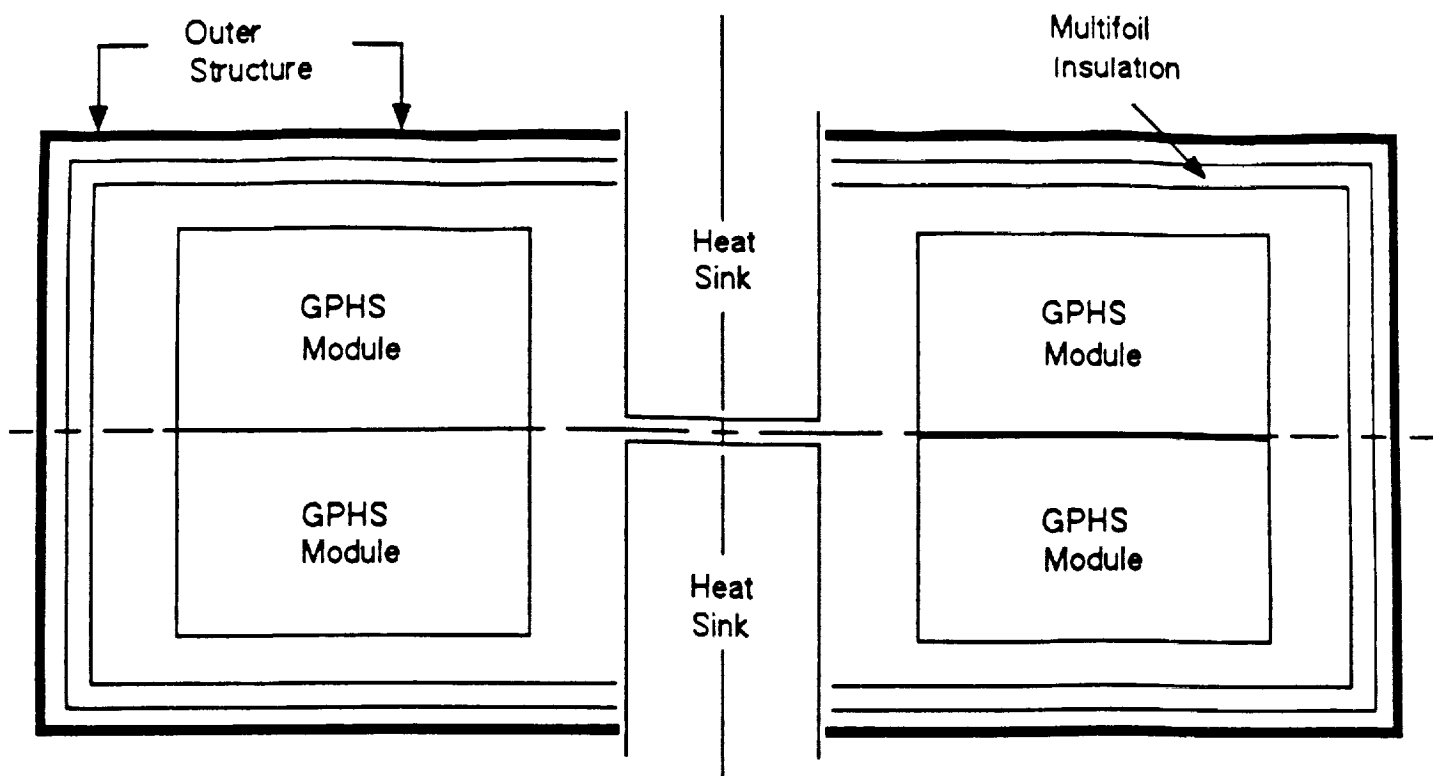


Figure 9.1a Symmetry of 500 W(e) GPHS/FPSE Power System From Side View

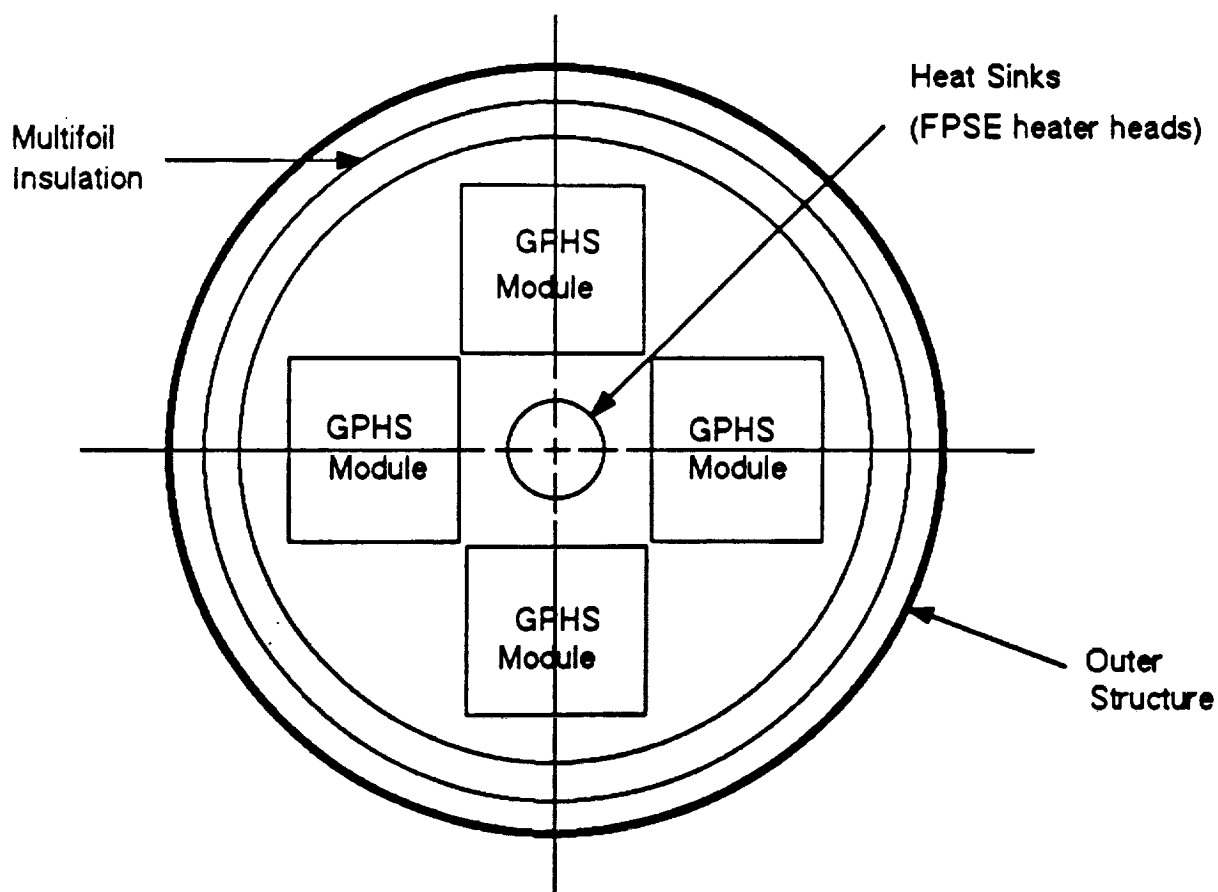


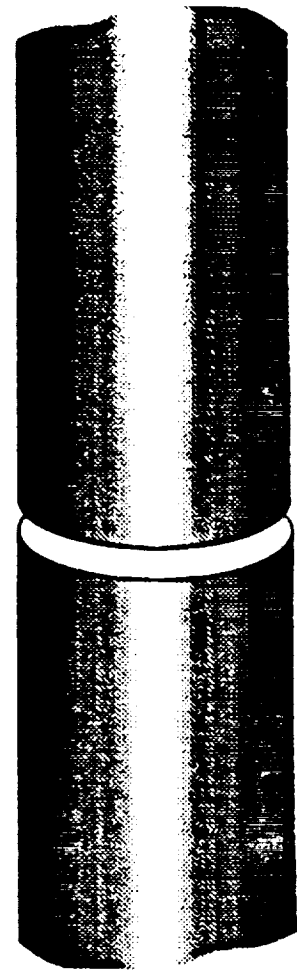
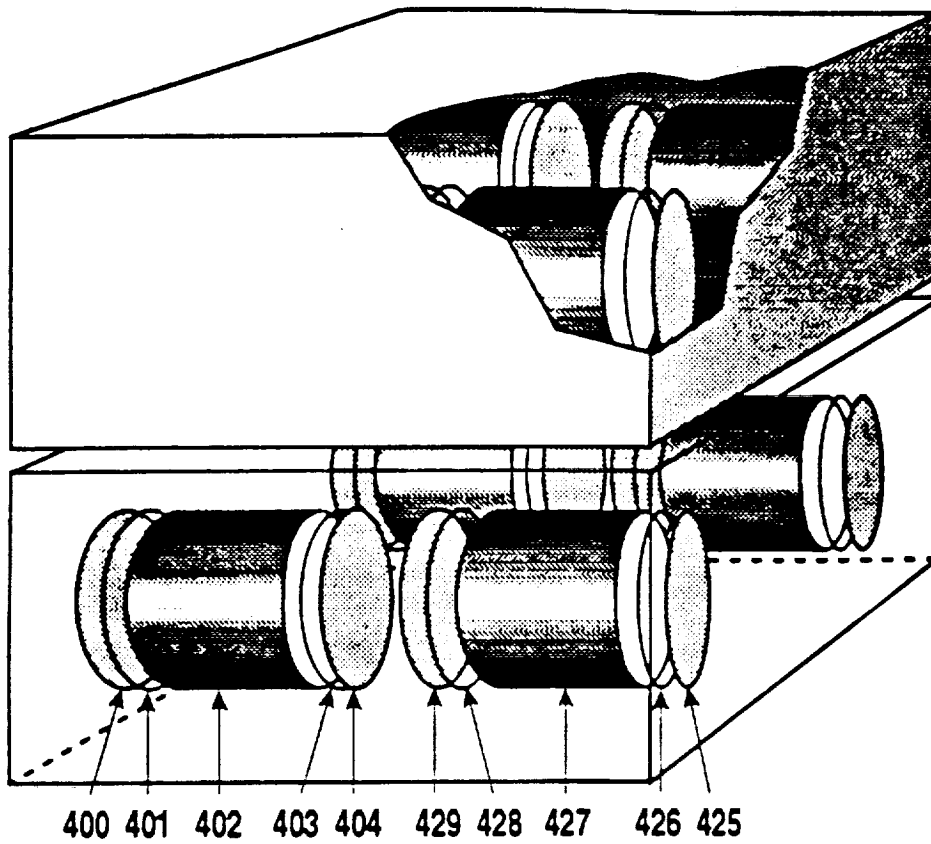
Figure 9.1b Symmetry of 500 W(e) GPHS/FPSE Power System From Top View

can be seen that analogous nodes in each GPHS module within each set of modules should have similar temperatures.

Temperatures of analogous nodes in each of the four sets of modules, and within each set of modules, were examined and found to be identical. Therefore, the number of nodal temperatures examined is reduced to the 10 nodes representing the fuel clad of the two fuel pellets on one side of one GPHS module.

Figure 9.2 depicts the arrangement of the fuel clad nodes in the 500 W_e power system configuration. The node shapes are identical to those described in Table 8.2 as part of the thermal analysis results for the 250 W_e power system. As shown in Figure 9.2, nodes numbered 425 to 429 represent the cladding of the fuel pellet closest to the heat sink and nodes 400 to 404 represent the cladding of the fuel pellet on the side of the GPHS module facing the power system enclosure.

The fuel clad nodal temperatures determined by the thermal analysis are shown in Figure 9.3 and listed in Table 9.2. As indicated in the figure and table, the temperatures of the fuel clad nodes are higher than the design goal temperature limit of 1573 K and higher than the fuel clad nodal temperatures determined for the fuel clad nodes in the 250 W_e system thermal model (See Figure 8.3 and Table 8.5).



Heat Sink Cylinders

Figure 9.2 Iridium Fuel Clad Nodal Arrangement

Table 9.2 500 W_e GPHS/FPSE Power System Fuel Clad Nodal Temperatures

Node Number	Temperature °F (K)		Node Number	Temperature °F (K)
400	2461 (1623)		425	2449 (1616)
401	2503 (1646)		426	2497 (1642)
402	2512 (1651)		427	2507 (1648)
403	2511 (1651)		428	2507 (1648)
404	2509 (1649)		429	2507 (1648)

After discussion with NASA LeRC engineers, it was decided that the temperatures shown by the thermal analysis are sufficiently close to the design goal temperature limit to warrant further investigation of the 500 W_e power system. The basis for this conclusion is the same as for the 250 W_e power system. Due to the close proximity of the fuel clad temperatures to the temperature limit, the ambiguous nature of the limit itself, and the conservative assumptions incorporated into the thermal model and used in the thermal analysis, modifications to the current thermal model should yield lower fuel clad nodal temperatures.

9.2.3 Temperatures Throughout the Power System Enclosure

Temperatures generated for various nodes throughout the 500 W_e power system, including some fuel clad nodes, are shown in Figure 9.4. The components and node

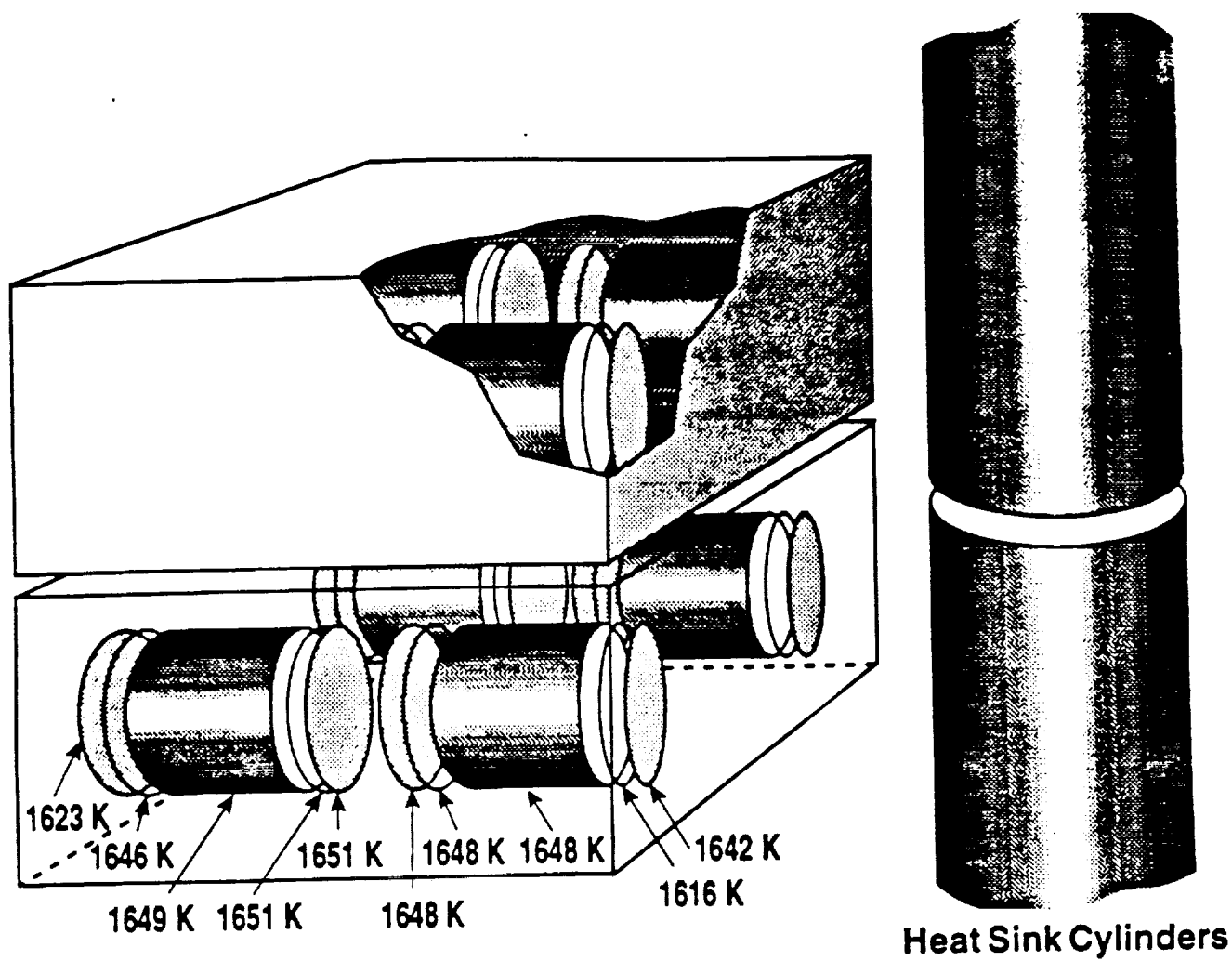


Figure 9.3 Iridium Fuel Clad Nodal Temperatures

numbers corresponding to the indicated temperatures were shown in Figures 7.1 and 7.2. As in the 250 W_θ system, temperatures throughout the power system are within acceptable ranges for materials considered for use in the power system.

A sensitivity analysis was not performed for the 500 W_θ power system. Due to the similarities between the two system configurations, it is expected that variance of the same key parameters should have similar effects on the fuel clad nodal temperatures. Since the degree to which the temperatures are affected may not be the same, a sensitivity analysis is recommended for future study.

9.2.4 Loss Of One Heat Sink Thermal Analysis

9.2.4.1 Description of Analysis

Since the 500 W_θ GPHS/FPSE power system has two heat sinks, an additional analysis was performed for this system in which one of the heat sinks is assumed to be lost. A significant assumption is necessary in order for the power system to continue operating under these conditions; each Stirling engine must be capable of handling the increased heat input that would be required to maintain the system in thermal equilibrium. With this assumption, under normal operating conditions, each Stirling engine would be operating at half its capacity. Whether or not Stirling engines could be developed to meet this requirement is beyond the scope of this analysis. Nevertheless, the analysis is performed and the fuel clad nodal temperatures are examined.

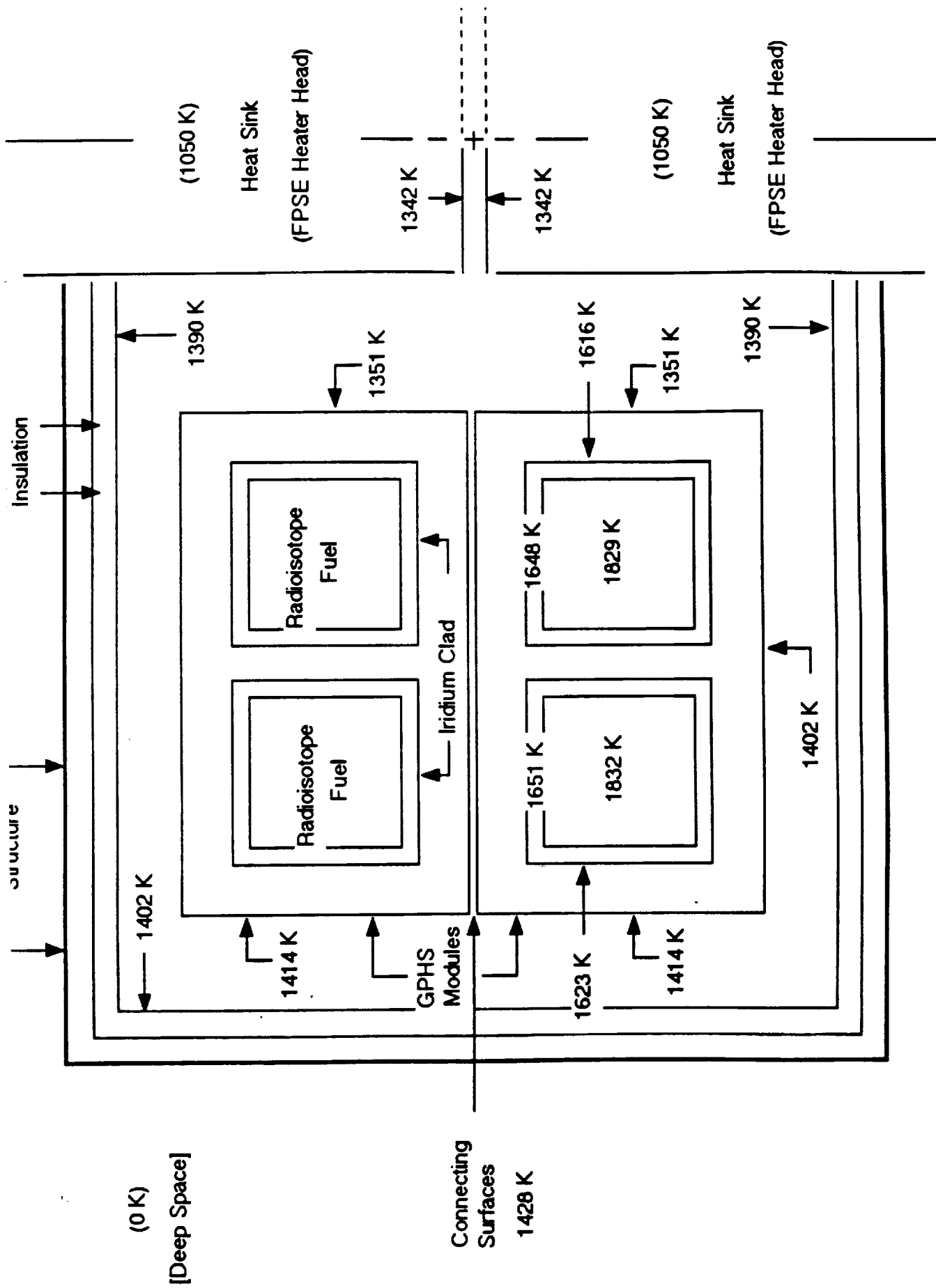


Figure 9.4 500 W(e) GPHS /FPSE Power System Nodal Temperatures

As an extension of the assumption described above, it is assumed that after failure of one of the heat sinks, the failed heat sink no longer removes heat from the system. The cylindrical node representing the failed heat sink is treated as an arithmetic node similar to the end cap nodes. The former heat sink node now reflects all thermal energy back into the power system enclosure.

9.2.4.2 Results From Loss of One Heat Sink Thermal Analysis

Since one heat sink is lost, the symmetry of the system shown in the side view of the power system (Figure 9.1a) is no longer applicable. Analogous nodes in each GPHS module within each set of modules are expected to have different temperatures. The symmetry shown in the top view of the power system (Figure 9.1b) still applies. Thus, the temperatures of the 20 nodes shown in Figure 9.2, which represent the fuel clad of the 4 pellets on one side of one set of the GPHS modules, are examined.

The fuel clad temperatures determined by the thermal analysis are listed in Table 9.3 and shown in Figure 9.5. As indicated in the figure and table, the temperatures of the fuel clad far exceed the design goal temperature limit of 1573 K. The temperatures, however, are not as unfavorable as they might first appear. If one were to use the temperature constraints suggested by the engineers at Mound Laboratories (See Subsection 2.2), the GPHS modules may be operated safely with temperatures as high as 1773 K. Using this criteria, the temperatures obtained from the thermal analysis are very close to falling

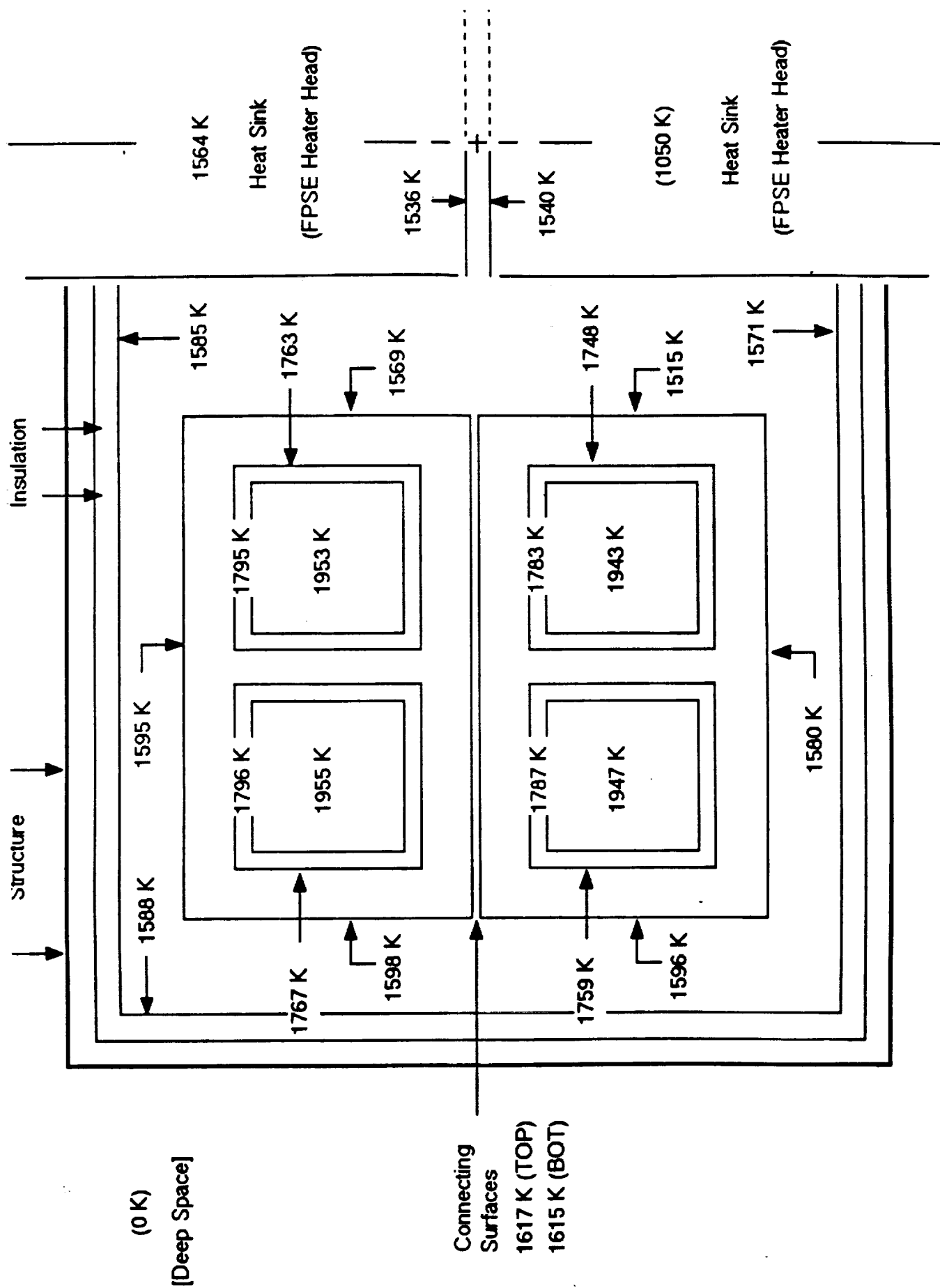


Figure 9.5 500 W(e) GPH S/FPSE Power System Nodal Temperatures
(Loss of One Heat Sink)

within the acceptable range.

Table 9.3 Fuel Clad Nodal Temperatures for the 500 W_e Power System After Failure of One Heat Sink

Node Number	Temperature °F (K)		Node Number	Temperature °F (K)
400	2707 (1759)		425	2686 (1748)
401	2748 (1782)		426	2739 (1777)
402	2758 (1787)		427	2750 (1783)
403	2757 (1787)		428	2751 (1784)
404	2756 (1786)		429	2753 (1785)
20400	2721 (1767)		20425	2713 (1763)
20401	2764 (1791)		20426	2760 (1789)
20402	2773 (1796)		20427	2771 (1795)
20403	2773 (1796)		20428	2771 (1795)
20404	2772 (1796)		20429	2771 (1795)

The temperature limits indicated in Table 2.1 also allowed for limited operation of the system with elevated fuel clad temperatures. The temperatures obtained from the thermal analysis indicate the system may be operated safely in this configuration for about 10 hours. It must be noted, however, that this thermal analysis has been a steady-state analysis. The time for the system to reach this steady-state has not been accounted for. If time constraints are applied, a transient analysis is necessary to determine the temperatures of the fuel clad nodes as a function of time as the steady-state conditions

are reached.

From the preceding thermal analysis, it is clear that an incontrovertible temperature limit for the fuel clad under normal operating conditions needs to be established. Only after the ambiguity of the temperature limit is removed can a final judgement be made concerning the acceptability of running the 500 W_e GPHS/FPSE power system with only one engine.

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1 250 W_e GPHS/FPSE Power System

As discussed in Section 8.0, for the thermal system modeled for the 250 W_e power system configuration, the iridium fuel clad temperatures in the GPHS modules were shown to be slightly higher (~20 K to ~50 K) than the design goal temperature of 1573 K. Due to the conservative assumptions used for the thermal analysis and the ambiguity of the temperature limit, the results of the analysis are considered favorable.

The sensitivity analysis has shown the relatively strong dependence of the fuel clad nodal temperatures on the heat sink parameters. The use of heat receptor fins on the Stirling engine heater head may be beneficial to the system design. The fins could be used to supply a larger surface area for the heat sink, thus reducing the heat sink heat flux. However, the fin temperatures may be slightly higher than the temperature used for the heat sink in the thermal model, so the advantage may not be as great as may be expected.

Another feature which should be investigated is the addition of surfaces which block the direct heat transfer between the GPHS modules. The current thermal model allows for the portion of each GPHS module extending beyond the end of the heat sink cylinder to directly exchange radiant energy with the other modules in the enclosure. Blocking this heat transfer path should result in lower fuel clad nodal temperatures. If heat receptor fins

which extend the length of the GPHS modules are incorporated into the heater head design, the fins would block a significant portion of the direct radiant heat transfer between the modules.

Before the model is revised to reflect the design changes mentioned above, it is recommended that a more detailed thermal analysis be performed with a modified version of the current thermal model. The modified thermal model should include nodes representing structural supports for the GPHS modules and nodes corresponding to a specific insulation material for the power system enclosure. As can be inferred from the heat loss variation performed as part of the sensitivity analysis, adding insulation to the thermal model should not significantly affect the fuel clad nodal temperatures. However, the impact of the added supports needs to be evaluated.

One of the primary assumptions used for the thermal analysis performed for this project was that the power system is operated in a vacuum environment (space). However, another potential mission application for the GPHS/FPSE power system may be use as the electrical power system for a Martian surface rover vehicle. Additional analysis would need to be done with the higher external heat sink temperature and the addition of the atmospheric gas in the power system enclosure. This would entail the addition of convective heat transfer inside and outside of the enclosure. In addition, since the Martian atmospheric gas is not transparent to thermal radiation, the effects of the reduced radiant heat transfer would need to be incorporated into the analysis.

10.2 500 W_e GPHS/FPSE Power System

The thermal analysis of the 500 W_e system thermal model has demonstrated fuel clad temperatures higher than the design goal temperature limit of 1573 K. Although the temperatures range from 43 K to 78 K higher than the design goal, the results of the analysis are considered favorable. These temperatures may prove to be perfectly acceptable once a firm operating temperature limit has been established. Even if the temperature limit is set at 1573 K, modifications to the current thermal model would be expected to yield temperatures below the prescribed limit.

The thermal analysis in which one of the heat sinks is lost has shown a significant increase in fuel clad temperatures from the normal operating temperatures. The fuel clad nodal temperatures range from 175 K to 223 K above the 1573 K design goal temperature limit. Based upon the criteria given in Table 2.1 of this report, indefinite operation of the system with fuel clad temperatures in this range is unacceptable. However, according to the same criteria, the system may be operated safely for a short time (~10 hours) with fuel clad temperatures in this range. It is also possible that these temperatures may be very close to being acceptable if the upper temperature limit for normal operation is set in accordance with the recommendations of the engineers at Mound Laboratories (see Subsection 2.2). They had suggested that the GPHS modules could be safely operated for extended periods (anticipated mission lifetimes) with fuel clad temperatures of up to 1773 K. If their assessment is accurate, minor modifications to the current 500 W_e system thermal model with only one heat sink should yield fuel clad temperatures below

1773 K.

The recommended modifications for future thermal analysis of the 500 W_e GPHS/FPSE power system are similar to those indicated for the 250 W_e power system. The modified thermal model should include nodes representing structural supports for the sets of GPHS modules and nodes corresponding to a specific insulation material for the power system enclosure. With two heat sinks in the 500 W_e system configuration, there is some blockage of direct thermal energy exchange between the sets of GPHS modules. Incorporating additional blocking surfaces should be investigated to determine the effect on the fuel clad temperatures.

Similar to the 250 W_e power system, if the 500 W_e GPHS/FPSE power system is considered for use as an electrical power system for a Martian surface rover vehicle, the current thermal model would need to be modified to reflect the changes described in the previous subsection.

Further analysis based on the results of this study should include investigation of even higher power level GPHS/FPSE systems. The higher power level systems should result in a lower specific weight (kg/kW_e) than the 250 W_e and 500 W_e power systems. The upper limit for the power level for a GPHS/FPSE power system remains to be determined. The limiting factors will be the fuel clad temperatures and the capabilities of the free-piston Stirling engine.

APPENDIX A

GPHS MATERIALS PROPERTIES

The physical properties of the GPHS materials which are required for the thermal analysis are given in Tables A.1 through A.8. These values were used in the GPHS thermal model developed by Pat Dunn (Appendix B) and incorporated into the GPHS/FPSE system thermal analysis performed for this project. The values were obtained from John A. Loffreda of the General Electric Company's Astro Space Division.

Table A.1 Fuel Pellet - PuO_2

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
100	0.242	0.6
572	0.254	0.643
752	0.266	0.659
932	0.315	0.676
1112	0.325	0.692
1292	0.335	0.709
1472	0.545	0.725
1652	0.59	0.742
1832	0.635	0.758
2012	0.681	0.775
2192	0.726	0.791
2500	0.747	0.819
3000	0.78	0.865
3500	0.814	0.911
4000	0.848	0.956
5000	0.915	0.956
20000	0.915	0.956

Table A.3 GIS Sides - FMPF

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
0	98.8	0.812
500	75.8	0.814
750	67.1	0.816
1000	59.6	0.818
1250	53.3	0.821
1500	48.3	0.824
1750	44.2	0.828
2000	40	0.832
2500	35	0.84
3000	30.8	0.848
4000	27.9	0.865
4800	26.6	0.882
20000	26.6	1

Table A.2 Fuel Clad - DOP-26 Ir

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
0	85	0.0838
1000	79	0.137
2000	76.5	0.191
3000	65.5	0.245
4000	65	0.298
20000	65	0.62

Table A.4 GIS End Cap (with holes) - FWPF

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
0	63.8	0.72
500	49.7	0.745
750	44	0.757
1000	38.7	0.769
1250	40.2	0.779
1500	30.9	0.789
1750	28.2	0.8
2000	26.2	0.81
2500	23.3	0.831
3000	22	0.851
4000	20.6	0.886
4800	20	0.912
20000	20	1

Table A.6 Aeroshell - FWPF X,Y Direction

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
0	98.8	0.812
500	75.8	0.814
750	67.1	0.816
1000	59.6	0.818
1250	53.3	0.821
1500	48.3	0.824
1750	44.2	0.828
2000	40	0.832
2500	35	0.84
3000	30.8	0.848
4000	27.9	0.865
4800	26.6	0.882
20000	26.6	1

Table A.5 Floating Membrane - FWPF

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
100	49.3	0.72
500	40.2	0.745
750	35.5	0.757
1000	31.2	0.769
1250	27.8	0.779
1500	25	0.789
1750	22.8	0.8
2000	21.1	0.81
2500	18.8	0.831
3000	17.8	0.851
4000	16.7	0.886
7800	16.1	0.912
20000	16.1	1

Table A.7 Aeroshell - FWPF Z Direction

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
0	77.4	0.642
500	60.3	0.675
750	53.5	0.696
1000	46.9	0.716
1250	41.7	0.734
1500	37.5	0.752
1750	34.2	0.77
2000	31.7	0.788
2500	28.3	0.82
3000	26.7	0.853
4000	25	0.905
4800	24.2	0.943
20000	24.2	1

Table A.8 Insulator Sleeve and Disc - CBCF-3

Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Emissivity
0	0.03545	0.8
392	0.052	0.8
572	0.061	0.8
752	0.071	0.8
932	0.081	0.8
1112	0.086	0.8
1292	0.091	0.8
1472	0.096	0.8
1652	0.101	0.8
1832	0.107	0.8
2012	0.112	0.8
2192	0.117	0.8
2372	0.122	0.8
2552	0.128	0.8
3000	0.141	0.8
4000	0.171	0.8
10000	0.7	0.8

APPENDIX B

GPHS MODULE THERMAL MODEL

This appendix contains three sections: (I) the SINDA input deck for the GPHS thermal model, (II) a series of diagrams depicting the nodal arrangement of the thermal model, and (III) thermal analysis results showing the temperatures of the GPHS interior nodes for four specific thermal environments. The thermal model and the thermal analyses were prepared specifically for use in this project by the Engineering Directorate of NASA Lewis Research Center.

I. SINDA INPUT DECK FOR GPHS THERMAL MODEL

```
BCD 3THERMAL LPCS
BCD 9 GPHS STEADY STATE THERMAL MODEL
BCD 9
END
BCD 3NODE DATA
REM
REM ***** AEROSHELL NODES *****
REM
GEN 100, 6, 1, 2000., -1.
REM
REM ***** SIDE "A" NODES *****
REM
GEN 600, 6, 1, 2000., -1.      $ FUEL PELLETT 1
GEN 625, 6, 1, 2000., -1.      $ FUEL PELLETT 2
GEN 400, 5, 1, 2000., -1.      $ IRIIDIUM CLADDING 1
GEN 425, 5, 1, 2000., -1.      $ IRIIDIUM CLADDING 2
GEN 500, 3, 1, 2000., -1.      $ FLOATING MEMBRANE
GEN 300, 3, 2, 2000., -1.      $ GIS
GEN 325, 3, 2, 2000., -1.      $ GIS
GEN 340, 3, 2, 2000., -1.      $ GIS
GEN 202, 2, 4, 2000., -1.      $ CBCF SLEEVE (EXTERIOR)
GEN 207, 2, 4, 2000., -1.      $ "
GEN 212, 2, 4, 2000., -1.      $ "
GEN 217, 2, 4, 2000., -1.      $ "
GEN 227, 2, 4, 2000., -1.      $ "
GEN 232, 2, 4, 2000., -1.      $ "
GEN 237, 2, 4, 2000., -1.      $ "
GEN 242, 2, 4, 2000., -1.      $ "
GEN 233, 4, 5, 2000., -1.      $ "
GEN 702, 2, 4, 2000., -1.      $ CBCF SLEEVE (INTERIOR)
GEN 707, 2, 4, 2000., -1.      $ "
GEN 712, 2, 4, 2000., -1.      $ "
```

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GEN 717, 2, 4, 2000., -1.    $    "
GEN 727, 2, 4, 2000., -1.    $    "
GEN 732, 2, 4, 2000., -1.    $    "
GEN 737, 2, 4, 2000., -1.    $    "
GEN 742, 2, 4, 2000., -1.    $    "
GEN 733, 4, 5, 2000., -1.    $    "
REM
REM ***** SIDE "B" NODES *****
REM
GEN 1600, 6, 1, 2000., -1.    $ FUEL PELLET 3
GEN 1625, 6, 1, 2000., -1.    $ FUEL PELLET 4
GEN 1400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 3
GEN 1425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 4
GEN 1500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 1300, 3, 2, 2000., -1.    $ GIS
GEN 1325, 3, 2, 2000., -1.    $ GIS
    1340,      2000., -1.    $ GIS
GEN 1202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 1207, 2, 4, 2000., -1.    $    "
GEN 1212, 2, 4, 2000., -1.    $    "
GEN 1217, 2, 4, 2000., -1.    $    "
GEN 1227, 2, 4, 2000., -1.    $    "
GEN 1232, 2, 4, 2000., -1.    $    "
GEN 1237, 2, 4, 2000., -1.    $    "
GEN 1242, 2, 4, 2000., -1.    $    "
GEN 1233, 4, 5, 2000., -1.    $    "
GEN 1702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 1707, 2, 4, 2000., -1.    $    "
GEN 1712, 2, 4, 2000., -1.    $    "
GEN 1717, 2, 4, 2000., -1.    $    "
GEN 1727, 2, 4, 2000., -1.    $    "
GEN 1732, 2, 4, 2000., -1.    $    "
GEN 1737, 2, 4, 2000., -1.    $    "
GEN 1742, 2, 4, 2000., -1.    $    "
GEN 1733, 4, 5, 2000., -1.    $    "
REM
REM ***** BOUNDARY NODES *****
REM
    -10000, 1850., 1.        $ RADIATION SINK
END
BCD 3CONDUCTOR DATA
REM
REM ***** AEROSHELL CONDUCTION *****
REM
SIM 101, 2, 1, 100, 0, 104, 1, A7, .01015
SIM 103, 2, 1, 102, 0, 104, 1, A7, .01015
DIM 105, 2, 1, 100, 0, 101, 2, A8, .05722, A7, .03982
DIM 107, 2, 1, 102, 0, 101, 2, A8, .05722, A7, .03982
DIM 109, 2, 1, 104, 0, 101, 2, A8, .05484, A7, .02996
DIM 111, 2, 1, 105, 0, 101, 2, A8, .05484, A7, .02996
REM
REM ***** SIDE "A" INTERIOR CONDUCTORS *****
REM
SIV 600,      600,      601,      A1, 1.033    $ PELLET 1
SIV 601,      601,      605,      A1, 2.221    $    "
SIV 602,      605,      602,      A1, 6.235    $    "
SIM 603, 2, 1, 600, 0, 603, 1, A1, .04736    $    "
SIM 605, 2, 1, 601, 0, 603, 1, A1, .04736    $    "
SIM 607, 2, 1, 605, 0, 603, 1, A1, .04736    $    "
SIV 625,      625,      626,      A1, 1.033    $ PELLET 2
SIV 626,      626,      630,      A1, 2.221    $    "
SIV 627,      630,      627,      A1, 6.235    $    "
SIM 628, 2, 1, 625, 0, 628, 1, A1, .04736    $    "
SIM 630, 2, 1, 626, 0, 628, 1, A1, .04736    $    "
SIM 632, 2, 1, 630, 0, 628, 1, A1, .04736    $    "
SIM 400, 2, 1, 400, 4, 401, 2, A2, .002899    $ CLADING 1
SIM 402, 2, 1, 401, 2, 402, 0, A2, .01301    $    "
SIM 425, 2, 1, 425, 4, 426, 2, A2, .002899    $ CLADING 2
SIM 427, 2, 1, 426, 2, 427, 0, A2, .01301    $    "

```


SIV	500,	500,	501,	A5,	.01773	\$ FLTNG MEM.
SIV	501,	501,	502,	A5,	.08229	\$ "
SIM	300, 2, 1,	300, 25,	302, 25,	A4,	.04604	\$ GIS
SIM	302, 2, 1,	302, 25,	304, 25,	A3,	.09564	\$ "
SIM	304, 2, 1,	304, 25,	340, 0,	A3,	.08398	\$ "
REM	\$ ** SLEEVE COND **					
SIM	200, 4, 1,	202, 5,	702, 5,	A6,	.6875	\$ THRU THICKNESS
SIM	204, 4, 1,	227, 5,	727, 5,	A6,	.6875	\$ "
SIM	208, 4, 1,	206, 5,	706, 5,	A6,	1.946	\$ "
SIM	212, 4, 1,	231, 5,	731, 5,	A6,	1.946	\$ "
SIM	216, 4, 1,	233, 5,	733, 5,	A6,	.6733	\$ "
SIM	240, 4, 1,	206, 5,	233, 5,	A6,	.01040	\$ ALONG LENGTH
SIM	248, 4, 1,	231, 5,	233, 5,	A6,	.01040	\$ "
SIM	256, 4, 1,	706, 5,	733, 5,	A6,	.01040	\$ "
SIM	264, 4, 1,	731, 5,	733, 5,	A6,	.01040	\$ "
SIM	268, 3, 1,	202, 5,	207, 5,	A6,	.002626	\$ CIRCUM ON ENDS
SIV	271,	217,	202,	A6,	.002626	\$ "
SIM	272, 3, 1,	227, 5,	232, 5,	A6,	.002626	\$ "
SIV	275,	242,	227,	A6,	.002626	\$ "
SIM	276, 3, 1,	702, 5,	707, 5,	A6,	.002626	\$ "
SIV	279,	717,	702,	A6,	.002626	\$ "
SIM	280, 3, 1,	727, 5,	732, 5,	A6,	.002626	\$ "
SIV	283,	742,	727,	A6,	.002626	\$ "
SIM	284, 3, 1,	206, 5,	211, 5,	A6,	.002858	\$ CIRCUM ON LENGTH
SIV	287,	221,	206,	A6,	.002858	\$ "
SIM	288, 3, 1,	231, 5,	236, 5,	A6,	.002858	\$ "
SIV	291,	246,	231,	A6,	.002858	\$ "
SIM	700, 3, 1,	706, 5,	711, 5,	A6,	.002858	\$ "
SIV	703,	721,	706,	A6,	.002858	\$ "
SIM	704, 3, 1,	731, 5,	736, 5,	A6,	.002858	\$ "
SIV	707,	746,	731,	A6,	.002858	\$ "
SIM	708, 3, 1,	233, 5,	238, 5,	A6,	.000989	\$ "
SIV	711,	248,	233,	A6,	.000989	\$ "
SIM	712, 3, 1,	733, 5,	738, 5,	A6,	.000989	\$ "
SIV	715,	748,	733,	A6,	.000989	\$ "
SIV	800,	602,	402,	A11,	4.398E-11	\$ SPT 1/CLD 1
SIM	801, 2, 1,	603, 1,	400, 4,	A11,	1.101E-11	\$ "
SIV	825,	627,	427,	A11,	4.398E-11	\$ SPT 2/CLD 2
SIM	826, 2, 1,	628, 1,	425, 4,	A11,	1.101E-11	\$ "
SIV	803,	402,	304,	A12,	5.176E-11	\$ CLAD 1/GIS
SIV	804,	400,	300,	A13,	1.288E-11	\$ "
SIV	828,	427,	329,	A12,	5.176E-11	\$ CLAD 2/GIS
SIV	829,	425,	325,	A13,	1.288E-11	\$ "
SIM	805, 2, 1,	404, 0,	500, 1,	A14,	0.644E-11	\$ CLAD 1/FM
SIM	830, 2, 1,	429, 0,	500, 1,	A14,	0.644E-11	\$ CLAD 2/FM
SIV	824,	502,	340,	A15,	1.949E-11	\$ FM/GIS
SIM	832, 4, 1,	300, 0,	702, 5,	A17,	5.615E-12	\$ GIS/SLEEVE
SIM	836, 4, 1,	325, 0,	727, 5,	A17,	5.615E-12	\$ "
SIM	840, 4, 1,	304, 0,	706, 5,	A16,	1.936E-11	\$ "
SIM	844, 4, 1,	329, 0,	731, 5,	A16,	1.936E-11	\$ "
SIM	848, 4, 1,	340, 0,	733, 5,	A16,	6.347E-12	\$ "
REM						
REM	***** SIDE "B" INTERIOR CONDUCTORS *****					
REM						
SIV	1600,	1600,	1601,	A1,	1.033	\$ PELLET 3
SIV	1601,	1601,	1605,	A1,	2.221	\$ "
SIV	1602,	1605,	1602,	A1,	6.235	\$ "
SIM	1603, 2, 1,	1600, 0,	1603, 1,	A1,	.04736	\$ "
SIM	1605, 2, 1,	1601, 0,	1603, 1,	A1,	.04736	\$ "
SIM	1607, 2, 1,	1605, 0,	1603, 1,	A1,	.04736	\$ "
SIV	1625,	1625,	1626,	A1,	1.033	\$ PELLET 4
SIV	1626,	1626,	1630,	A1,	2.221	\$ "
SIV	1627,	1630,	1627,	A1,	6.235	\$ "
SIM	1628, 2, 1,	1625, 0,	1628, 1,	A1,	.04736	\$ "
SIM	1630, 2, 1,	1626, 0,	1628, 1,	A1,	.04736	\$ "
SIM	1632, 2, 1,	1630, 0,	1628, 1,	A1,	.04736	\$ "
SIM	1400, 2, 1,	1400, 4,	1401, 2,	A2,	.002899	\$ CLADING 3
SIM	1402, 2, 1,	1401, 2,	1402, 0,	A2,	.01301	\$ "
SIM	1425, 2, 1,	1425, 4,	1426, 2,	A2,	.002899	\$ CLADING 4

```

SIM 1427, 2, 1, 1426, 2, 1427, 0, A2, .01301 $ "
SIV 1500, 1500, 1501, A5, .01773 $ FLTNG MEM.
SIV 1501, 1501, 1502, A5, .08229 $ "
SIM 1300, 2, 1, 1300, 25, 1302, 25, A4, .04604 $ GIS
SIM 1302, 2, 1, 1302, 25, 1304, 25, A3, .09564 $ "
SIM 1304, 2, 1, 1304, 25, 1340, 0, A3, .08398 $ "
REM $ ** SLEEVE COND **
SIM 1200, 4, 1, 1202, 5, 1702, 5, A6, .6875 $ THRU THICKNESS
SIM 1204, 4, 1, 1227, 5, 1727, 5, A6, .6875 $ "
SIM 1208, 4, 1, 1206, 5, 1706, 5, A6, 1.946 $ "
SIM 1212, 4, 1, 1231, 5, 1731, 5, A6, 1.946 $ "
SIM 1216, 4, 1, 1233, 5, 1733, 5, A6, .6733 $ "
SIM 1240, 4, 1, 1206, 5, 1233, 5, A6, .01040 $ ALONG LENGTH
SIM 1248, 4, 1, 1231, 5, 1233, 5, A6, .01040 $ "
SIM 1256, 4, 1, 1706, 5, 1733, 5, A6, .01040 $ "
SIM 1264, 4, 1, 1731, 5, 1733, 5, A6, .01040 $ "
SIM 1268, 3, 1, 1202, 5, 1207, 5, A6, .002626 $ CIRCUM ON ENDS
SIV 1271, 1217, 1202, A6, .002626 $ "
SIM 1272, 3, 1, 1227, 5, 1232, 5, A6, .002626 $ "
SIV 1275, 1242, 1227, A6, .002626 $ "
SIM 1276, 3, 1, 1702, 5, 1707, 5, A6, .002626 $ "
SIV 1279, 1717, 1702, A6, .002626 $ "
SIM 1280, 3, 1, 1727, 5, 1732, 5, A6, .002626 $ "
SIV 1283, 1742, 1727, A6, .002626 $ "
SIM 1284, 3, 1, 1206, 5, 1211, 5, A6, .002858 $ CRCM ON LENGTH
SIV 1287, 1221, 1206, A6, .002858 $ "
SIM 1288, 3, 1, 1231, 5, 1236, 5, A6, .002858 $ "
SIV 1291, 1246, 1231, A6, .002858 $ "
SIM 1700, 3, 1, 1706, 5, 1711, 5, A6, .002858 $ "
SIV 1703, 1721, 1706, A6, .002858 $ "
SIM 1704, 3, 1, 1731, 5, 1736, 5, A6, .002858 $ "
SIV 1707, 1746, 1731, A6, .002858 $ "
SIM 1708, 3, 1, 1233, 5, 1238, 5, A6, .000989 $ "
SIV 1711, 1248, 1233, A6, .000989 $ "
SIM 1712, 3, 1, 1733, 5, 1738, 5, A6, .000989 $ "
SIV 1715, 1748, 1733, A6, .000989 $ "
SIV -1800, 1602, 1402, A11, 4.398E-11 $ SPT 3/CLD 3
SIM -1801, 2, 1, 1603, 1, 1400, 4, A11, 1.101E-11 $ "
SIV -1825, 1627, 1427, A11, 4.398E-11 $ SPT 4/CLD 4
SIM -1826, 2, 1, 1628, 1, 1425, 4, A11, 1.101E-11 $ "
SIV -1803, 1402, 1304, A12, 5.176E-11 $ CLAD 3/GIS
SIV -1804, 1400, 1300, A13, 1.288E-11 $ "
SIV -1828, 1427, 1329, A12, 5.176E-11 $ CLAD 4/GIS
SIV -1829, 1425, 1325, A13, 1.288E-11 $ "
SIM -1805, 2, 1, 1404, 0, 1500, 1, A14, 0.644E-11 $ CLAD 3/FM
SIM -1830, 2, 1, 1429, 0, 1500, 1, A14, 0.644E-11 $ CLAD 4/FM
SIV -1824, 1502, 1340, A15, 1.949E-11 $ FM/GIS
SIM -1832, 4, 1, 1300, 0, 1702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -1836, 4, 1, 1325, 0, 1727, 5, A17, 5.615E-12 $ "
SIM -1840, 4, 1, 1304, 0, 1706, 5, A16, 1.936E-11 $ "
SIM -1844, 4, 1, 1329, 0, 1731, 5, A16, 1.936E-11 $ "
SIM -1848, 4, 1, 1340, 0, 1733, 5, A16, 6.347E-12 $ "
REM
REM *** RADK'S BETWEEN SLEEVES AND AEROSHELL ***
REM
SIM - 901, 2, 1, 206, 10, 101, 2, A18, 2.142E-11 $ CYL/AS
SIM - 903, 2, 1, 1206, 10, 101, 2, A18, 2.142E-11 $ "
SIM - 905, 2, 1, 221, 990, 105, -1, A19, 2.142E-11 $ "
SIM - 907, 2, 1, 231, 10, 101, 2, A18, 2.142E-11 $ "
SIM - 909, 2, 1, 1231, 10, 101, 2, A18, 2.142E-11 $ "
SIM - 911, 2, 1, 246, 990, 105, -1, A19, 2.142E-11 $ "
SIM - 913, 2, 1, 233, 10, 101, 2, A18, 7.022E-12 $ "
SIM - 915, 2, 1, 1233, 10, 101, 2, A18, 7.022E-12 $ "
SIM - 917, 2, 1, 248, 990, 105, -1, A19, 7.022E-12 $ "
SIM - 919, 4, 1, 202, 5, 100, 0, A19, 6.873E-12 $ END
CAPS/AS
SIM - 923, 4, 1, 1202, 5, 100, 0, A19, 6.873E-12 $ "
SIM - 927, 4, 1, 227, 5, 102, 0, A19, 6.873E-12 $ "
SIM - 931, 4, 1, 1227, 5, 102, 0, A19, 6.873E-12 $ "

```

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- 935,      238,      1248,      4.682E-12 $ SLV A
      /SLV B
GEN - 936, 2, 1, 211, 25,1221,27, 1.428E-11 $ "
REM
REM      *** RADK'S TO THE ENVIRONMENT ***
REM
SIV -1000, 100, 10000, A20, 9.518E-11 $ AEROSHELL FRONT
SIV -1001, 102, 10000, A20, 9.518E-11 $ AEROSHELL BACK
SIV -1002, 101, 10000, A21, 1.670E-10 $ AEROSHELL TOP
SIV -1003, 103, 10000, A21, 1.670E-10 $ AEROSHELL BOTTOM
SIV -1004, 104, 10000, A20, 9.125E-11 $ AEROSHELL RIGHT SIDE
SIV -1005, 105, 10000, A20, 9.125E-11 $ AEROSHELL LEFT SIDE
END
BCD 3CONSTANTS DATA
1, 62.5 $ POWER DISSIPATION PER PELLET (WATTS)
NDIM=1000,ARLXCA=.05,DRLXCA=.05,NLOOP=1000
BALENG=4.26
END
BCD 3ARRAY DATA
REM FUEL PELLET K(BTU/FT-HR-F) VS. T(F)
1, -1000., .242, 100., .242, 572., .254, 752., .266
932., .315, 1112., .325, 1292., .335, 1472., .345
1652., .59, 1832., .635, 2012., .681, 2192., .726
2500., .747, 3000., .78, 3500., .814, 4000., .848
5000., .915, 20000., .915, END
REM IRIIDIUM CLADING K(BTU/FT-HR-F) VS. T(F)
2, -1000., 85., 0., 85., 1000., 79., 2000., 76.5
3000., 65.5, 4000., 65., 20000., 65., END
REM GIS SIDES K(BTU/FT-HR-F) VS. T(F)
3, -1000., 98.8, 0., 98.8, 500., 75.8, 750., 67.1
1000., 59.6, 1250., 53.3, 1500., 48.3, 1750., 44.2
2000., 40., 2500., 35., 3000., 30.8, 4000., 27.9
4800., 26.6, 20000., 26.6, END
REM GIS END SECTION WITH HOLES K(BTU/FT-HR-F) VS. T(F)
4, -1000., 63.8, 0., 63.8, 500., 49.7, 750., 44.
1000., 38.7, 1250., 40.2, 1500., 30.9, 1750., 28.2
2000., 26.2, 2500., 23.3, 3000., 22., 4000., 20.6
7800., 20., 20000., 20., END
REM FLOATING MEMBRANE K(BTU/FT-HR-F) VS. T(F)
5, -1000., 49.3, 100., 49.3, 500., 40.2, 750., 35.5
1000., 31.2, 1250., 27.8, 1500., 25., 1750., 22.8
2000., 21.1, 2500., 18.8, 3000., 17.8, 4000., 16.7
4800., 16.1, 20000., 16.1, END
REM CBCF SLEEVE K(BTU/FT-HR-F) VS. T(F)
6, -1000., .03545, 0., .03545, 392., .052, 572., .061
752., .071, 932., .081, 1112., .086, 1292., .091
1472., .096, 1652., .101, 1832., .107, 2012., .112
2192., .117, 2372., .122, 2552., .128, 3000., .141
4000., .171, 10000., .7, END
REM AEROSHELL X,Y DIR K(BTU/FT-HR-F) VS. T(F)
7, -1000., 98.8, 0., 98.8, 500., 75.8, 750., 67.1
1000., 59.6, 1250., 53.3, 1500., 48.3, 1750., 44.2
2000., 40.0, 2500., 35.0, 3000., 30.8, 4000., 27.9
4800., 26.6, 20000., 26.6, END
REM AEROSHELL Z DIR K(BTU/FT-HR-F) VS. T(F)
8, -1000., 77.4, 0., 77.4, 500., 60.3, 750., 53.3
1000., 46.9, 1250., 41.7, 1500., 37.5, 1750., 34.2
2000., 31.7, 2500., 28.3, 3000., 26.7, 4000., 25.
4800., 24.2, 20000., 24.2, END
REM "SCRIPT F" VS. T(F), PELLET-TO-CLADDING
11, -1000., .0794, 0., .0794, 1000., .129, 2000., .181
3000., .236, 4000., .294, 20000., .603, END
REM "SCRIPT F" VS. T(F), CLADDING-TO-GIS SIDES
12, -1000., .0822, 0., .0822, 1000., .133, 2000., .184
3000., .235, 4000., .285, 20000., .620, END
REM "SCRIPT F" VS. T(F), CLADDING-TO-GIS ENDS
13, -1000., .0812, 0., .0812, 1000., .132, 2000., .183
3000., .235, 4000., .287, 20000., .620, END
REM "SCRIPT F" VS. T(F), CLADDING-TO-FLOATING MEMBRANE

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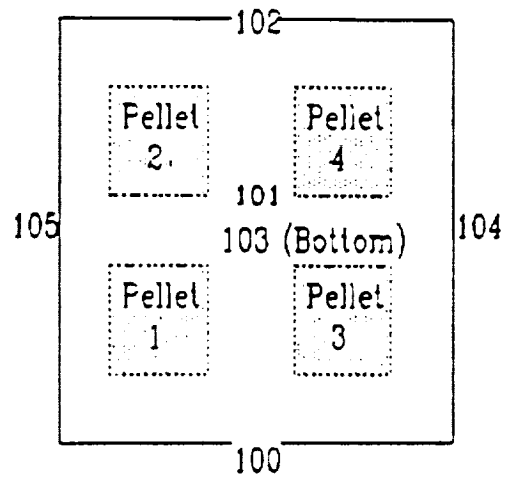
14, -1000., .0812, 0., .0812, 1000., .132, 2000., .183
3000., .235, 4000., .287, 20000., .620, END
REM "SCRIPT F" VS. T(F), FLOATING MEMBRANE-TO-GIS
15, -1000., .617, 0., .617, 500., .637, 750., .647
1000., .657, 1250., .666, 1500., .669, 1750., .686
2000., .696, 2500., .717, 3000., .738, 4000., .778
4800., .813, 20000., 1., END
REM "SCRIPT F" VS. T(F), GIS SIDES-TO-CBCF SLEEVE
16, -1000., .675, 0., .675, 500., .676, 750., .678
1000., .679, 1250., .681, 1500., .683, 1750., .686
2000., .689, 2500., .694, 3000., .700, 4000., .711
20000., .8, END
REM "SCRIPT F" VS. T(F), GIS ENDS-TO-CBCF SLEEVE
17, -1000., .610, 0., .610, 500., .628, 750., .637
1000., .645, 1250., .652, 1500., .659, 1750., .667
2000., .674, 2500., .688, 3000., .702, 4000., .725
7800., .743, 20000., .8, END
REM "SCRIPT F" VS. T(F), CBCF SLEEVE-TO-AEROSHELL TOP & BOT
18, -1000., .553, 0., .553, 500., .578, 750., .593
1000., .607, 1250., .620, 1500., .633, 1750., .646
2000., .658, 2500., .680, 3000., .703, 4000., .738
4800., .763, 20000., .8, END
REM "SCRIPT F" VS. T(F), CBCF SLEEVE-TO-AEROSHELL SIDES
19, -1000., .675, 0., .675, 500., .676, 750., .678
1000., .679, 1250., .681, 1500., .683, 1750., .686
2000., .689, 2500., .694, 3000., .700, 4000., .711
4800., .723, 20000., .8, END
REM EMISSIVITY VS. T(F), AEROSHELL X,Y DIRECTION
20, -1000., .812, 0., .812, 500., .814, 750., .816
1000., .818, 1250., .821, 1500., .824, 1750., .828
2000., .832, 2500., .84, 3000., .848, 4000., .865
4800., .882, 20000., 1., END
REM EMISSIVITY VS. T(F), AEROSHELL Z DIRECTION
21, -1000., .642, 0., .642, 500., .675, 750., .696
1000., .716, 1250., .734, 1500., .752, 1750., .77
2000., .788, 2500., .82, 3000., .853, 4000., .905
4800., .943, 20000., 1., END

END
BCD 3EXECUTION
STDSTL
END
BCD 3VARIABLES 1
REM STORE POWER DISSIPATIONS
M Q600 = XK1 * 3.412 / 3.
M Q601 = XK1 * 3.412 / 3.
M Q605 = XK1 * 3.412 / 3.
M Q625 = XK1 * 3.412 / 3.
M Q626 = XK1 * 3.412 / 3.
M Q630 = XK1 * 3.412 / 3.
M Q1600 = XK1 * 3.412 / 3.
M Q1601 = XK1 * 3.412 / 3.
M Q1605 = XK1 * 3.412 / 3.
M Q1625 = XK1 * 3.412 / 3.
M Q1626 = XK1 * 3.412 / 3.
M Q1630 = XK1 * 3.412 / 3.
END
BCD 3VARIABLES 2
END
BCD 3OUTPUT CALLS.
QIPRNT
TPRINT
END
BCD 3END OF DATA

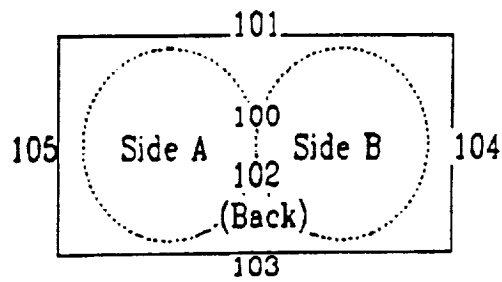
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II. GPHS THERMAL MODEL NODAL ARRANGEMENT

Aeroshell Nodal Arrangement
&
General Model Layout



Top View



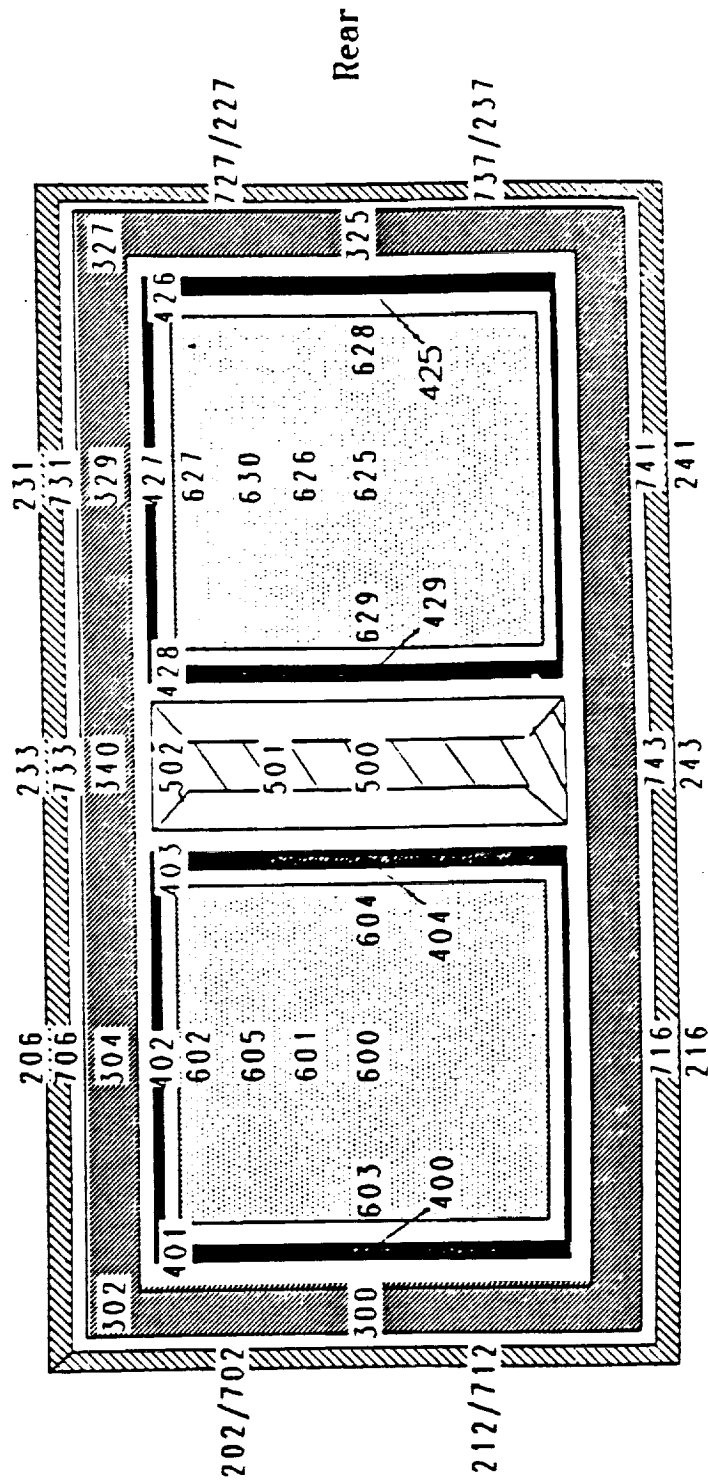
Front View

CPIIS Interior

Nodal Arrangement

(Side "A")

Top



Bottom

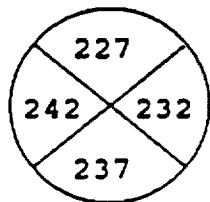
Note: Add 1000 for Side "B" nodes

CBCF Sleeve

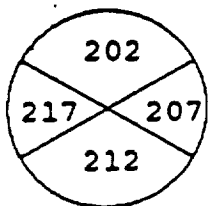
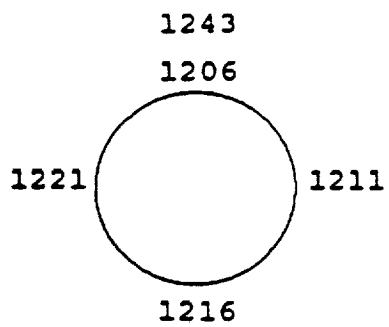
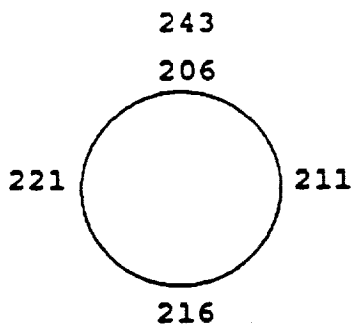
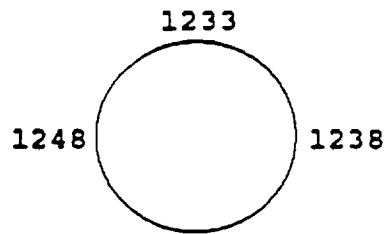
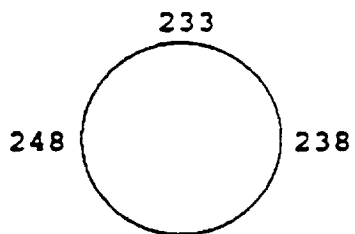
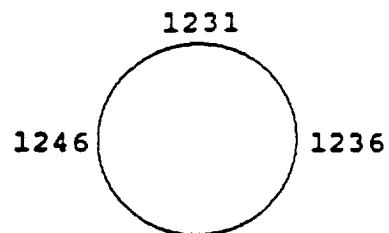
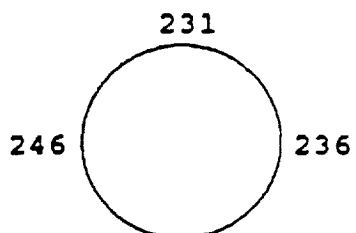
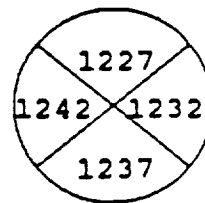
Nodal Arrangement

Note: Exterior nodes shown
 Interior nodes are 700 series
 View Looking from the front

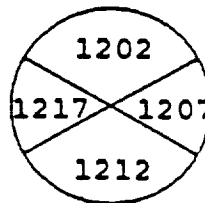
Rear



End Sections



End Sections



Front

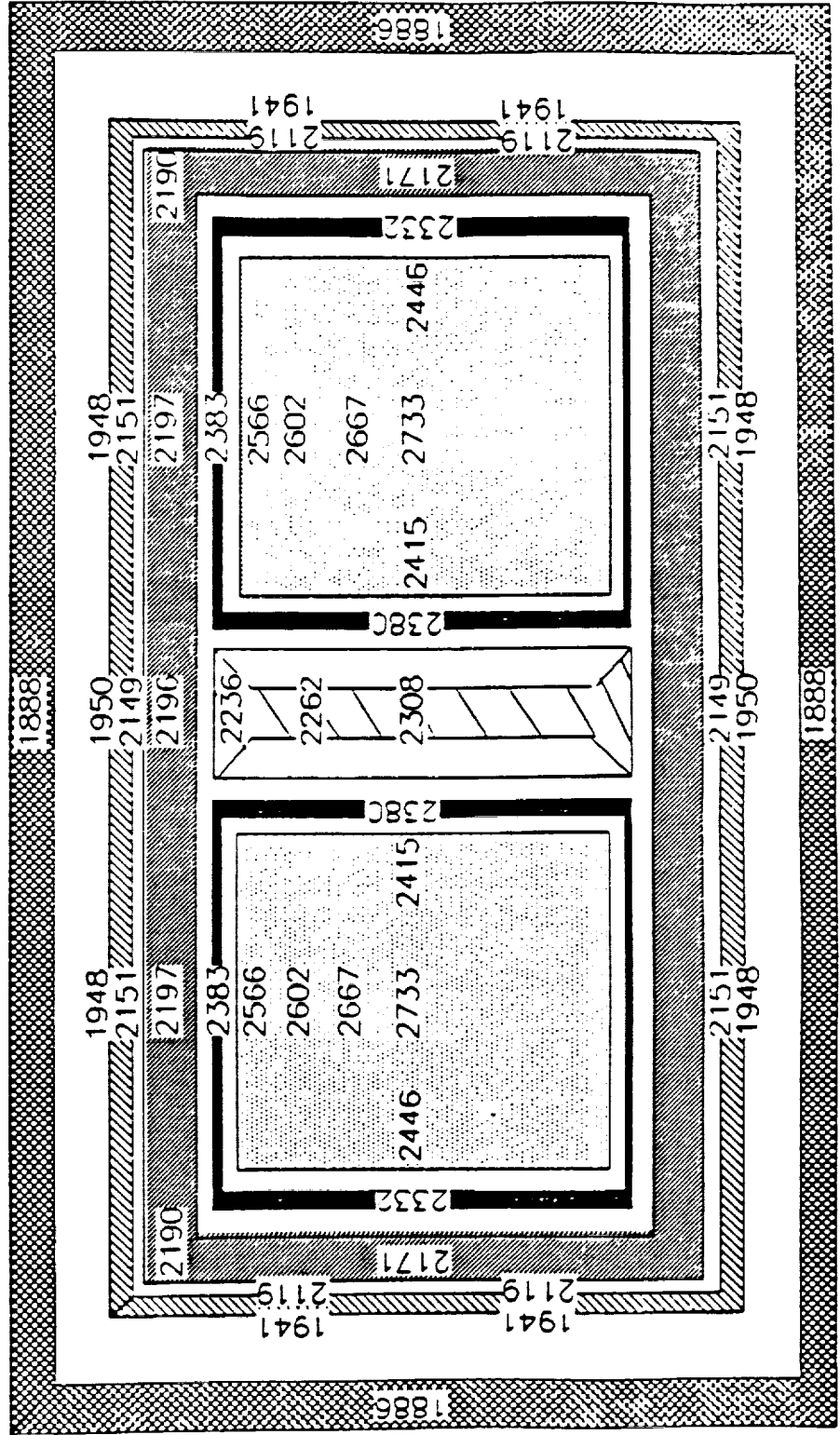
Side "A"

Side "B"

III. GPHS INTERIOR NODAL TEMPERATURES FOR FOUR DIFFERENT THERMAL ENVIRONMENTS

GPHS Temperatures

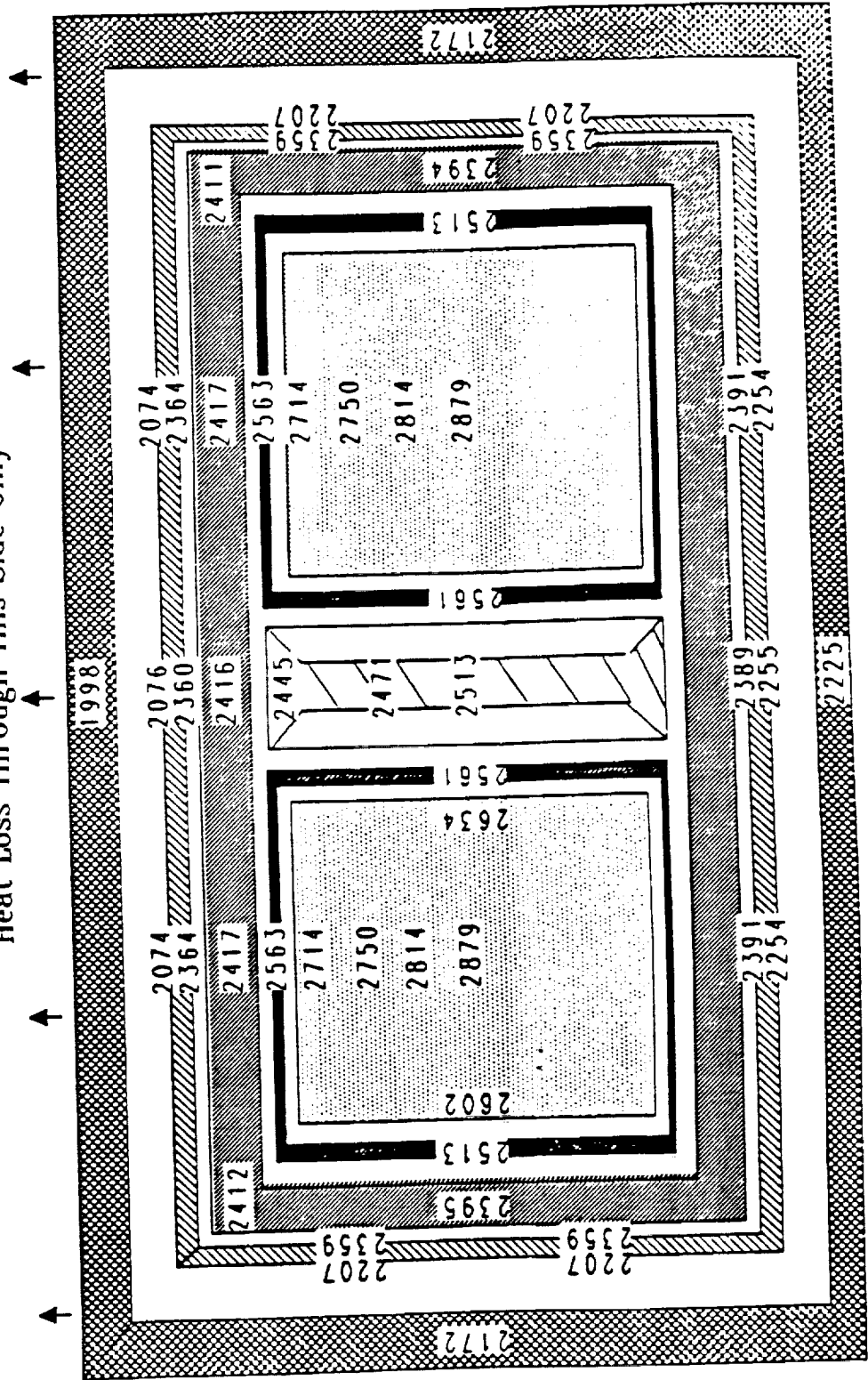
Comparison case with C.E.
Heat loss on all sides
Environment at 1850 Deg F
Temperatures in Deg F



GPHS Temperatures

Environment at 1880 Deg F
Temperatures in Deg F

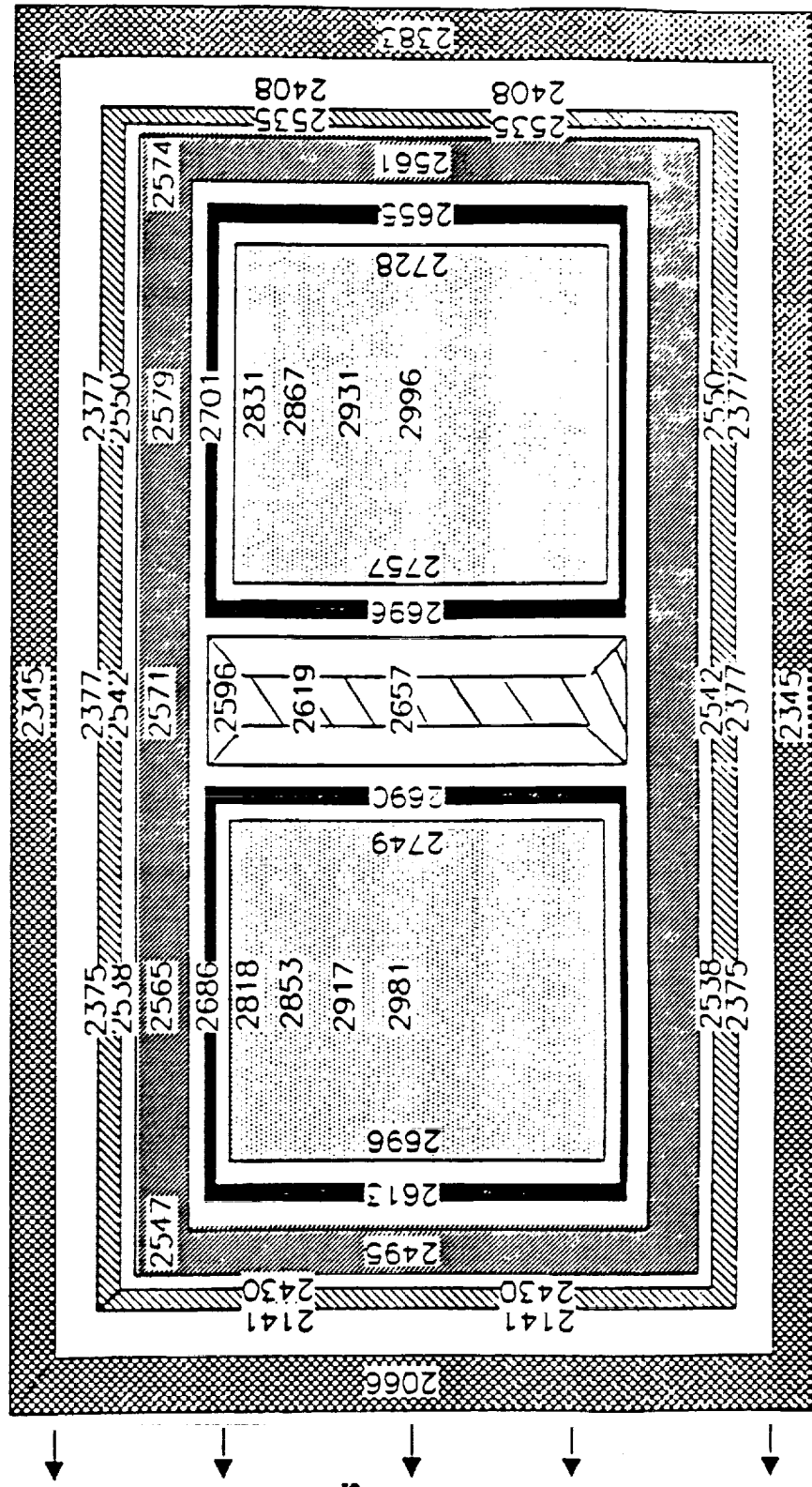
Heat Loss Through This Side Only



GPHS Temperatures

Environment at 1880 Deg F

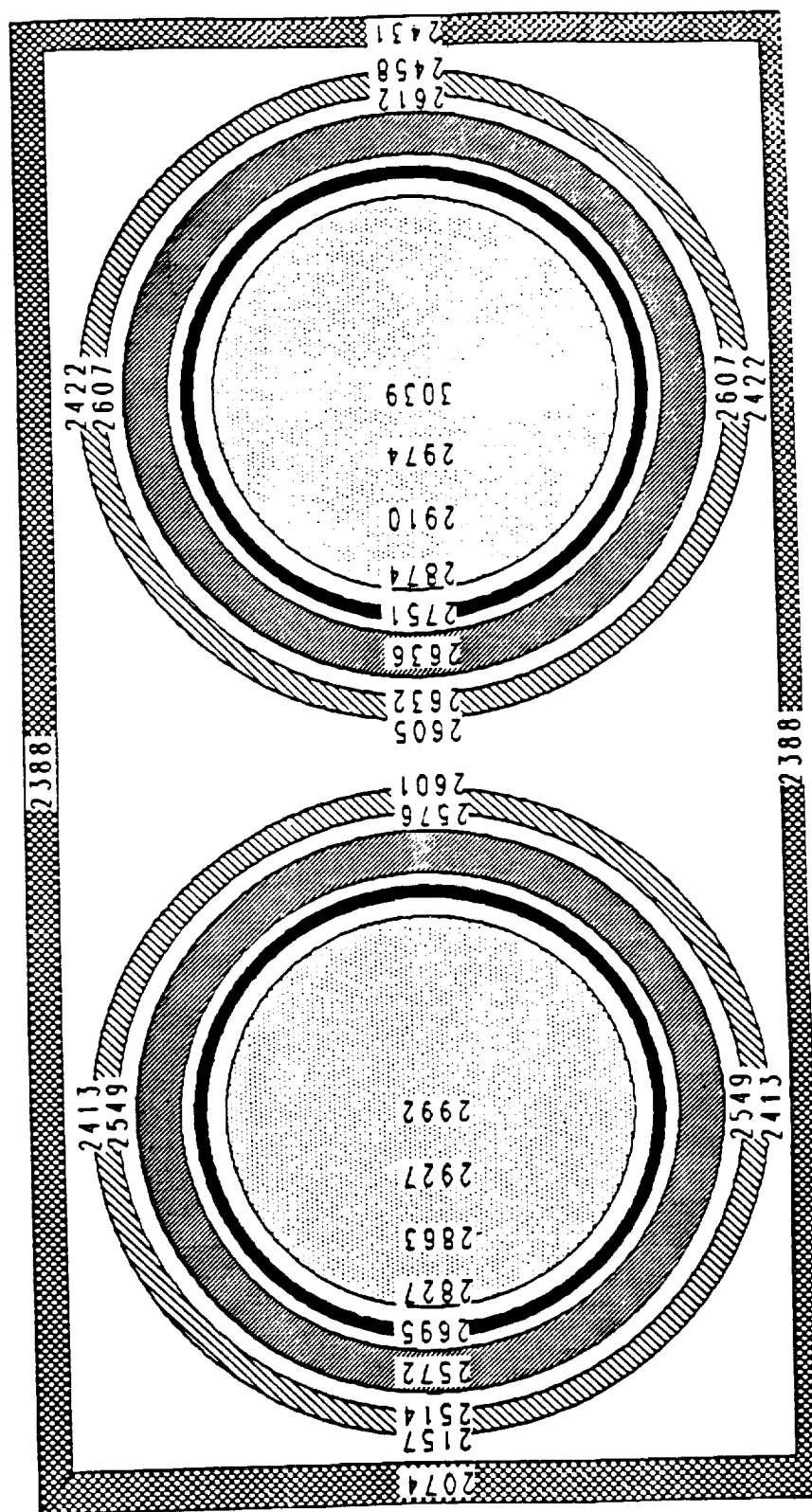
Temperatures in Deg F



GPHS Temperatures

Environment at 1880 Deg F

Temperatures in Deg F



B-15

Heat Loss
Through
This Side
Only

APPENDIX C

TRASYS INPUT FILE FOR THERMAL ANALYSIS OF THE 250 W_e GPHS/FPSE POWER SYSTEM

```
HEADER OPTIONS DATA
TITLE GPHS/FPSE 250We POWER SYSTEM
MODEL = DOPS
RSO = RSOUT2
HEADER SURFACE DATA
C
D      0.08333
C
BCS    BSRL      $ HEAT SINK CYLINDER
S      SURFN=10100
      TYPE=CYL, ACTIVE=OUT
      ALPHA=1.0, EMISS=0.8
      SHADE=BOTH, BSHADE=BOTH
      R = 1.0
      ZMIN = 0.0
      ZMAX = 3.0
      AXMIN = 0.0
      AXMAX = 360.0
      NNAX = 1
      NNZ = 1
C
C
BCS    BSHD      $ DISK-SHAPED END CAP TO HEAT SINK
S      SURFN=10200
      TYPE=DISK, ACTIVE=TOP
      ALPHA=1.0, EMISS=0.2
      SHADE=BOTH, BSHADE=BOTH
      Z = 3.0
      RMIN = 0.0
      RMAX = 1.0
      AXMIN = 0.0
      AXMAX = 360.0
      NNAX = 1
      NNR = 1
C
C
BCS    GPHS1      $ GPHS RADIOISOTOPE HEAT SOURCE
S      SURFN = 100
      TYPE = BOX6, ACTIVE = OUT
      ALPHA = 1.0, EMISS = 0.8
      SHADE = BOTH, BSHADE = BOTH
      P1 = 3.826, 2.09, 3.668
C
C
BCS    GPHS2      $ GPHS RADIOISOTOPE HEAT SOURCE
S      SURFN = 2100
      TYPE = BOX6, ACTIVE = OUT
      ALPHA = 1.0, EMISS = 0.8
      SHADE = BOTH, BSHADE = BOTH
      P1 = 3.826, 2.09, 3.668
C
```

```

C
BCS  GPHS3      $ GPHS RADIOISOTOPE HEAT SOURCE
S    SURFN = 4100
      TYPE = BOX6, ACTIVE = OUT
      ALPHA = 1.0, EMISS = 0.8
      SHADE = BOTH, BSHADE = BOTH
      P1 = 3.826, 2.09, 3.668

C
C
BCS  GPHS4      $ GPHS RADIOISOTOPE HEAT SOURCE
S    SURFN = 6100
      TYPE = BOX6, ACTIVE = OUT
      ALPHA = 1.0, EMISS = 0.8
      SHADE = BOTH, BSHADE = BOTH
      P1 = 3.826, 2.09, 3.668

C
C
BCS  WALL       $ CYLINDRICAL INNER SURFACE OF
C                      POWER SYSTEM ENCLOSURE
S    SURFN = 10400
      TYPE = CYL, ACTIVE = IN
      ALPHA = 1.0, EMISS = 0.1
      SHADE = BOTH, BSHADE = BOTH
      R = 4.8
      ZMIN = 0.0
      ZMAX = 4.668
      AXMIN = 0.0
      AXMAX = 360.0
      NNAX = 1
      NNZ = 1

C
C
BCS  BSRT       $ DISK-SHAPED INNER SURFACE ON HEATER
C                      HEAD END OF POWER SYSTEM ENCLOSURE
S    SURFN = 10500
      TYPE=DISK, ACTIVE=TOP
      ALPHA=1.0, EMISS=0.1
      SHADE=BOTH, BSHADE=BOTH
      Z = 0.0
      RMIN = 1.0
      RMAX = 4.8
      AXMIN = 0.0
      AXMAX = 360.0
      NNAX = 1
      NNR = 1

C
C
BCS  TSRT       $ DISK-SHAPED INNER SURFACE AT OPPOSITE
C                      END OF POWER SYSTEM ENCLOSURE
S    SURFN = 10600
      TYPE=DISK, ACTIVE=BOTTOM
      ALPHA=1.0, EMISS=0.1
      SHADE=BOTH, BSHADE=BOTH
      Z = 4.668
      RMIN = 0.0
      RMAX = 4.8
      AXMIN = 0.0
      AXMAX = 360.0
      NNAX = 1
      NNR = 1

C
C
C    HEADER BCS DATA
C
C    POSITIONING OF GPHS MODULES
C
BCS  BSRL,      0.0, 0.0, 0.0, 0.0, 0.0, 0.0
BCS  BSHD,      0.0, 0.0, 0.0, 0.0, 0.0, 0.0
BCS  GPHS1,     5.126524E-3, 0.230576, 4.16667E-2, 0.0, 0.0, -45.0

```



```

BCS  GPHS2,  -0.230576,  5.126524E-3,  4.16667E-2,  0.0,  0.0,  45.0
BCS  GPHS3,  -5.126524E-3, -0.230576,  4.16667E-2,  0.0,  0.0,  135.0
BCS  GPHS4,   0.230576, -5.126524E-3,  4.16667E-2,  0.0,  0.0, -135.0
BCS  WALL,   0.0,  0.0,  0.0,  0.0,  0.0,  0.0
BCS  BSRT,   0.0,  0.0,  0.0,  0.0,  0.0,  0.0
BCS  TSRT,   0.0,  0.0,  0.0,  0.0,  0.0,  0.0

```

HEADER OPERATIONS DATA

```

BUILD DOPS,BSRL,BSHD,GPHS1,GPHS2,GPHS3,GPHS4,WALL,BSRT,TSRT

```

```

C
C  CALCULATION OF GEOMETRIC CONFIGURATION FACTORS
L  FFCAL
C

```

```

C  GRAY BODY CALCULATIONS
CALL GBDATA('BOTH',' ','FF')
L  GBCAL
C

```

```

C  CALCULATION OF RADIATION CONDUCTORS
CALL RKDATA(' ',' ',0.0,'NO',0.0,0.0,'YES',' ')
L  RKCAL
C

```

```

END OF DATA

```


APPENDIX D

SINDA INPUT DECK FOR THERMAL ANALYSIS OF THE 250 W_e GPHS/FPSE POWER SYSTEM

```

BCD 3THERMAL LPCS
BCD 9 GPHS/FPSE 250We STEADY STATE THERMAL MODEL
BCD 9
END
REM *****
BCD 3NODE DATA
REM *****
REM
REM
REM ***** POWER SYSTEM ENCLOSURE NODES *****
REM
GEN 10400, 3, 100, 1500., -1.    $ INTERIOR
GEN 10700, 3, 100, 200., -1.    $ EXTERIOR
REM
REM
REM ***** END CAP TO HEAT SINK NODE *****
REM
10200,          1500., -1.    $ DISK
REM
REM
REM ***** BOUNDARY NODES *****
REM
-99999,          -460., 1.    $ RADIATING TO SPACE
-10100,          1430., 1.    $ HEAT SINK CYLINDER
REM
REM
REM ***** GPHS 1 NODES *****
REM
REM
REM ***** AEROSHELL #1 NODES *****
REM
GEN 100, 6, 1, 2000., -1.
REM
REM ***** SIDE #1A NODES *****
REM
GEN 600, 6, 1, 2000., -1.    $ FUEL PELLET 1
GEN 625, 6, 1, 2000., -1.    $ FUEL PELLET 2
GEN 400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 1
GEN 425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 2
GEN 500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 300, 3, 2, 2000., -1.    $ GIS
GEN 325, 3, 2, 2000., -1.    $ GIS
GEN 340, 3, 2, 2000., -1.    $ GIS
GEN 202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 207, 2, 4, 2000., -1.    $ "
GEN 212, 2, 4, 2000., -1.    $ "
GEN 217, 2, 4, 2000., -1.    $ "
GEN 227, 2, 4, 2000., -1.    $ "
GEN 232, 2, 4, 2000., -1.    $ "
GEN 237, 2, 4, 2000., -1.    $ "

```

```

GEN 242, 2, 4, 2000., -1.    $    "
GEN 233, 4, 5, 2000., -1.    $    "
GEN 702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 707, 2, 4, 2000., -1.    $    "
GEN 712, 2, 4, 2000., -1.    $    "
GEN 717, 2, 4, 2000., -1.    $    "
GEN 727, 2, 4, 2000., -1.    $    "
GEN 732, 2, 4, 2000., -1.    $    "
GEN 737, 2, 4, 2000., -1.    $    "
GEN 742, 2, 4, 2000., -1.    $    "
GEN 733, 4, 5, 2000., -1.    $    "
REM
REM ***** SIDE "18" NODES *****
REM
GEN 1600, 6, 1, 2000., -1.    $ FUEL PELLET 3
GEN 1625, 6, 1, 2000., -1.    $ FUEL PELLET 4
GEN 1400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 3
GEN 1425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 4
GEN 1500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 1300, 3, 2, 2000., -1.    $ GIS
GEN 1325, 3, 2, 2000., -1.    $ GIS
   1340,      2000., -1.    $ GIS
GEN 1202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 1207, 2, 4, 2000., -1.    $    "
GEN 1212, 2, 4, 2000., -1.    $    "
GEN 1217, 2, 4, 2000., -1.    $    "
GEN 1227, 2, 4, 2000., -1.    $    "
GEN 1232, 2, 4, 2000., -1.    $    "
GEN 1237, 2, 4, 2000., -1.    $    "
GEN 1242, 2, 4, 2000., -1.    $    "
GEN 1233, 4, 5, 2000., -1.    $    "
GEN 1702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 1707, 2, 4, 2000., -1.    $    "
GEN 1712, 2, 4, 2000., -1.    $    "
GEN 1717, 2, 4, 2000., -1.    $    "
GEN 1727, 2, 4, 2000., -1.    $    "
GEN 1732, 2, 4, 2000., -1.    $    "
GEN 1737, 2, 4, 2000., -1.    $    "
GEN 1742, 2, 4, 2000., -1.    $    "
GEN 1733, 4, 5, 2000., -1.    $    "
REM
REM ***** GPHS 2 NODES *****
REM
REM ***** AEROSHELL #2 NODES *****
REM
GEN 2100, 6, 1, 2000., -1.
REM
REM ***** SIDE "2A" NODES *****
REM
GEN 2600, 6, 1, 2000., -1.    $ FUEL PELLET 1
GEN 2625, 6, 1, 2000., -1.    $ FUEL PELLET 2
GEN 2400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 1
GEN 2425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 2
GEN 2500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 2300, 3, 2, 2000., -1.    $ GIS
GEN 2325, 3, 2, 2000., -1.    $ GIS
   2340,      2000., -1.    $ GIS
GEN 2202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 2207, 2, 4, 2000., -1.    $    "
GEN 2212, 2, 4, 2000., -1.    $    "
GEN 2217, 2, 4, 2000., -1.    $    "
GEN 2227, 2, 4, 2000., -1.    $    "
GEN 2232, 2, 4, 2000., -1.    $    "
GEN 2237, 2, 4, 2000., -1.    $    "
GEN 2242, 2, 4, 2000., -1.    $    "
GEN 2233, 4, 5, 2000., -1.    $    "
GEN 2702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)

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GEN 2707, 2, 4, 2000., -1.    $    "
GEN 2712, 2, 4, 2000., -1.    $    "
GEN 2717, 2, 4, 2000., -1.    $    "
GEN 2727, 2, 4, 2000., -1.    $    "
GEN 2732, 2, 4, 2000., -1.    $    "
GEN 2737, 2, 4, 2000., -1.    $    "
GEN 2742, 2, 4, 2000., -1.    $    "
GEN 2733, 4, 5, 2000., -1.    $    "
REM
REM ***** SIDE "28" NODES *****
REM
GEN 3600, 6, 1, 2000., -1.    $ FUEL PELLET 3
GEN 3625, 6, 1, 2000., -1.    $ FUEL PELLET 4
GEN 3400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 3
GEN 3425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 4
GEN 3500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 3300, 3, 2, 2000., -1.    $ GIS
GEN 3325, 3, 2, 2000., -1.    $ GIS
GEN 3340, 3, 2, 2000., -1.    $ GIS
GEN 3202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 3207, 2, 4, 2000., -1.    $    "
GEN 3212, 2, 4, 2000., -1.    $    "
GEN 3217, 2, 4, 2000., -1.    $    "
GEN 3227, 2, 4, 2000., -1.    $    "
GEN 3232, 2, 4, 2000., -1.    $    "
GEN 3237, 2, 4, 2000., -1.    $    "
GEN 3242, 2, 4, 2000., -1.    $    "
GEN 3233, 4, 5, 2000., -1.    $    "
GEN 3702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 3707, 2, 4, 2000., -1.    $    "
GEN 3712, 2, 4, 2000., -1.    $    "
GEN 3717, 2, 4, 2000., -1.    $    "
GEN 3727, 2, 4, 2000., -1.    $    "
GEN 3732, 2, 4, 2000., -1.    $    "
GEN 3737, 2, 4, 2000., -1.    $    "
GEN 3742, 2, 4, 2000., -1.    $    "
GEN 3733, 4, 5, 2000., -1.    $    "
REM
REM ***** GPHS 3 NODES *****
REM
REM ***** AEROSHELL #3 NODES *****
REM
GEN 4100, 6, 1, 2000., -1.
REM
REM ***** SIDE "3A" NODES *****
REM
GEN 4600, 6, 1, 2000., -1.    $ FUEL PELLET 1
GEN 4625, 6, 1, 2000., -1.    $ FUEL PELLET 2
GEN 4400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 1
GEN 4425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 2
GEN 4500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 4300, 3, 2, 2000., -1.    $ GIS
GEN 4325, 3, 2, 2000., -1.    $ GIS
GEN 4340, 3, 2, 2000., -1.    $ GIS
GEN 4202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 4207, 2, 4, 2000., -1.    $    "
GEN 4212, 2, 4, 2000., -1.    $    "
GEN 4217, 2, 4, 2000., -1.    $    "
GEN 4227, 2, 4, 2000., -1.    $    "
GEN 4232, 2, 4, 2000., -1.    $    "
GEN 4237, 2, 4, 2000., -1.    $    "
GEN 4242, 2, 4, 2000., -1.    $    "
GEN 4233, 4, 5, 2000., -1.    $    "
GEN 4702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 4707, 2, 4, 2000., -1.    $    "
GEN 4712, 2, 4, 2000., -1.    $    "
GEN 4717, 2, 4, 2000., -1.    $    "

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GEN 4727, 2, 4, 2000., -1.    $    "
GEN 4732, 2, 4, 2000., -1.    $    "
GEN 4737, 2, 4, 2000., -1.    $    "
GEN 4742, 2, 4, 2000., -1.    $    "
GEN 4733, 4, 5, 2000., -1.    $    "
REM
REM ***** SIDE "38" NODES *****
REM
GEN 5600, 6, 1, 2000., -1.    $ FUEL PELLET 3
GEN 5625, 6, 1, 2000., -1.    $ FUEL PELLET 4
GEN 5400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 3
GEN 5425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 4
GEN 5500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 5300, 3, 2, 2000., -1.    $ GIS
GEN 5325, 3, 2, 2000., -1.    $ GIS
    5340,      2000., -1.    $ GIS
GEN 5202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 5207, 2, 4, 2000., -1.    $    "
GEN 5212, 2, 4, 2000., -1.    $    "
GEN 5217, 2, 4, 2000., -1.    $    "
GEN 5227, 2, 4, 2000., -1.    $    "
GEN 5232, 2, 4, 2000., -1.    $    "
GEN 5237, 2, 4, 2000., -1.    $    "
GEN 5242, 2, 4, 2000., -1.    $    "
GEN 5233, 4, 5, 2000., -1.    $    "
GEN 5702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 5707, 2, 4, 2000., -1.    $    "
GEN 5712, 2, 4, 2000., -1.    $    "
GEN 5717, 2, 4, 2000., -1.    $    "
GEN 5727, 2, 4, 2000., -1.    $    "
GEN 5732, 2, 4, 2000., -1.    $    "
GEN 5737, 2, 4, 2000., -1.    $    "
GEN 5742, 2, 4, 2000., -1.    $    "
GEN 5733, 4, 5, 2000., -1.    $    "
REM
REM ***** GPHS 4 NODES *****
REM
REM ***** AEROSHELL #4 NODES *****
REM
GEN 6100, 6, 1, 2000., -1.
REM
REM ***** SIDE "4A" NODES *****
REM
GEN 6600, 6, 1, 2000., -1.    $ FUEL PELLET 1
GEN 6625, 6, 1, 2000., -1.    $ FUEL PELLET 2
GEN 6400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 1
GEN 6425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 2
GEN 6500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 6300, 3, 2, 2000., -1.    $ GIS
GEN 6325, 3, 2, 2000., -1.    $ GIS
    6340,      2000., -1.    $ GIS
GEN 6202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 6207, 2, 4, 2000., -1.    $    "
GEN 6212, 2, 4, 2000., -1.    $    "
GEN 6217, 2, 4, 2000., -1.    $    "
GEN 6227, 2, 4, 2000., -1.    $    "
GEN 6232, 2, 4, 2000., -1.    $    "
GEN 6237, 2, 4, 2000., -1.    $    "
GEN 6242, 2, 4, 2000., -1.    $    "
GEN 6233, 4, 5, 2000., -1.    $    "
GEN 6702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 6707, 2, 4, 2000., -1.    $    "
GEN 6712, 2, 4, 2000., -1.    $    "
GEN 6717, 2, 4, 2000., -1.    $    "
GEN 6727, 2, 4, 2000., -1.    $    "
GEN 6732, 2, 4, 2000., -1.    $    "
GEN 6737, 2, 4, 2000., -1.    $    "

```

```

GEN 6742, 2, 4, 2000., -1.    $    "
GEN 6733, 4, 5, 2000., -1.    $    "
REM
REM ***** SIDE "4B" NODES *****
REM
GEN 7600, 6, 1, 2000., -1.    $ FUEL PELLET 3
GEN 7625, 6, 1, 2000., -1.    $ FUEL PELLET 4
GEN 7400, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 3
GEN 7425, 5, 1, 2000., -1.    $ IRIIDIUM CLADDING 4
GEN 7500, 3, 1, 2000., -1.    $ FLOATING MEMBRANE
GEN 7300, 3, 2, 2000., -1.    $ GIS
GEN 7325, 3, 2, 2000., -1.    $ GIS
GEN 7340, 3, 2, 2000., -1.    $ GIS
GEN 7202, 2, 4, 2000., -1.    $ CBCF SLEEVE (EXTERIOR)
GEN 7207, 2, 4, 2000., -1.    $    "
GEN 7212, 2, 4, 2000., -1.    $    "
GEN 7217, 2, 4, 2000., -1.    $    "
GEN 7227, 2, 4, 2000., -1.    $    "
GEN 7232, 2, 4, 2000., -1.    $    "
GEN 7237, 2, 4, 2000., -1.    $    "
GEN 7242, 2, 4, 2000., -1.    $    "
GEN 7233, 4, 5, 2000., -1.    $    "
GEN 7702, 2, 4, 2000., -1.    $ CBCF SLEEVE (INTERIOR)
GEN 7707, 2, 4, 2000., -1.    $    "
GEN 7712, 2, 4, 2000., -1.    $    "
GEN 7717, 2, 4, 2000., -1.    $    "
GEN 7727, 2, 4, 2000., -1.    $    "
GEN 7732, 2, 4, 2000., -1.    $    "
GEN 7737, 2, 4, 2000., -1.    $    "
GEN 7742, 2, 4, 2000., -1.    $    "
GEN 7733, 4, 5, 2000., -1.    $    "
REM
REM
REM
END
REM*****
REM*****
REM
BCD 3CONDUCTOR DATA
REM
REM*****
REM*****
REM
REM *****
REM          CONDUCTANCE BETWEEN INTERIOR AND
REM          EXTERIOR OF POWER SYSTEM ENCLOSURE
REM *****
REM
-10401, 10400, 10700, 1.0E-25    $ CYLINDER
-10501, 10500, 10800, 1.0E-25    $ HEAT SINK END
-10601, 10600, 10900, 1.0E-25    $ OPPOSITE END
REM
REM
REM *****
REM          RADKS TO SPACE
REM *****
REM
-10701, 10700, 99999, 2.496E-10  $ CYL: STRUCTURE - SPACE
-10801, 10800, 99999, 1.094E-10  $ BOT: STRUCTURE - SPACE
-10901, 10900, 99999, 1.131E-10  $ TOP: STRUCTURE - SPACE
REM
REM
REM *****
REM          CONDUCTION DATA FOR HEAT TRANSFER
REM          BETWEEN SIDES OF EACH GPHS BLOCK
REM *****
REM
REM ***** AEROSHELL 1 CONDUCTION *****

```

```

REM
SIM 8101, 2, 1, 100, 0, 104, -2, A7, .01015
SIM 8103, 2, 1, 105, 0, 104, -2, A7, .01015
DIM 8105, 2, 1, 100, 0, 101, 2, A8, .05722, A7, .03982
DIM 8107, 2, 1, 105, 0, 101, 2, A8, .05722, A7, .03982
DIM 8109, 2, 1, 104, 0, 101, 2, A8, .05484, A7, .02996
DIM 8111, 2, 1, 102, 0, 101, 2, A8, .05484, A7, .02996
REM
REM
REM ***** AEROSHELL 2 CONDUCTION *****
REM
SIM 2101, 2, 1, 2100, 0, 2104, -2, A7, .01015
SIM 2103, 2, 1, 2105, 0, 2104, -2, A7, .01015
DIM 2105, 2, 1, 2100, 0, 2101, 2, A8, .05722, A7, .03982
DIM 2107, 2, 1, 2105, 0, 2101, 2, A8, .05722, A7, .03982
DIM 2109, 2, 1, 2104, 0, 2101, 2, A8, .05484, A7, .02996
DIM 2111, 2, 1, 2102, 0, 2101, 2, A8, .05484, A7, .02996
REM
REM
REM ***** AEROSHELL 3 CONDUCTION *****
REM
SIM 4101, 2, 1, 4100, 0, 4104, -2, A7, .01015
SIM 4103, 2, 1, 4105, 0, 4104, -2, A7, .01015
DIM 4105, 2, 1, 4100, 0, 4101, 2, A8, .05722, A7, .03982
DIM 4107, 2, 1, 4105, 0, 4101, 2, A8, .05722, A7, .03982
DIM 4109, 2, 1, 4104, 0, 4101, 2, A8, .05484, A7, .02996
DIM 4111, 2, 1, 4102, 0, 4101, 2, A8, .05484, A7, .02996
REM
REM
REM ***** AEROSHELL 4 CONDUCTION *****
REM
SIM 6101, 2, 1, 6100, 0, 6104, -2, A7, .01015
SIM 6103, 2, 1, 6105, 0, 6104, -2, A7, .01015
DIM 6105, 2, 1, 6100, 0, 6101, 2, A8, .05722, A7, .03982
DIM 6107, 2, 1, 6105, 0, 6101, 2, A8, .05722, A7, .03982
DIM 6109, 2, 1, 6104, 0, 6101, 2, A8, .05484, A7, .02996
DIM 6111, 2, 1, 6102, 0, 6101, 2, A8, .05484, A7, .02996
REM
REM *****
REM CONDUCTANCES BETWEEN INTERIOR
REM NODES OF GPHS BLOCKS
REM *****
REM
REM ** GPHS 1, SIDE "A" INTERIOR CONDUCTORS **
REM
SIV 8600, 600, 601, A1, 1.033 $ PELLET 1
SIV 8601, 601, 605, A1, 2.221 $ "
SIV 8602, 605, 602, A1, 6.235 $ "
SIM 8603, 2, 1, 600, 0, 603, 1, A1, .04736 $ "
SIM 8605, 2, 1, 601, 0, 603, 1, A1, .04736 $ "
SIM 8607, 2, 1, 605, 0, 603, 1, A1, .04736 $ "
SIV 8625, 625, 626, A1, 1.033 $ PELLET 2
SIV 8626, 626, 630, A1, 2.221 $ "
SIV 8627, 630, 627, A1, 6.235 $ "
SIM 8628, 2, 1, 625, 0, 628, 1, A1, .04736 $ "
SIM 8630, 2, 1, 626, 0, 628, 1, A1, .04736 $ "
SIM 8632, 2, 1, 630, 0, 628, 1, A1, .04736 $ "
SIM 8400, 2, 1, 400, 4, 401, 2, A2, .002899 $ CLADDING 1
SIM 8402, 2, 1, 401, 2, 402, 0, A2, .01301 $ "
SIM 8425, 2, 1, 425, 4, 426, 2, A2, .002899 $ CLADDING 2
SIM 8427, 2, 1, 426, 2, 427, 0, A2, .01301 $ "
SIV 8500, 500, 501, A5, .01773 $ FLOATING MEN.
SIV 8501, 501, 502, A5, .08229 $ "
SIM 8300, 2, 1, 300, 25, 302, 25, A4, .04604 $ GIS
SIM 8302, 2, 1, 302, 25, 304, 25, A3, .09564 $ "
SIM 8304, 2, 1, 304, 25, 340, 0, A3, .08398 $ "
REM
SIM 8200, 4, 1, 202, 5, 702, 5, A6, .6875 $ ** SLEEVE COND **
SIM 8204, 4, 1, 227, 5, 727, 5, A6, .6875 $ THRU THICKNESS

```


SIM	8208,	4,	1,	206,	5,	706,	5,	A6,	1.946	\$	"
SIM	8212,	4,	1,	231,	5,	731,	5,	A6,	1.946	\$	"
SIM	8216,	4,	1,	233,	5,	733,	5,	A6,	.6733	\$	"
SIM	8240,	4,	1,	206,	5,	233,	5,	A6,	.01040	\$	ALONG LENGTH
SIM	8248,	4,	1,	231,	5,	233,	5,	A6,	.01040	\$	"
SIM	8256,	4,	1,	706,	5,	733,	5,	A6,	.01040	\$	"
SIM	8264,	4,	1,	731,	5,	733,	5,	A6,	.01040	\$	"
SIM	8268,	3,	1,	202,	5,	207,	5,	A6,	.002626\$		CIRCUMF ON ENDS
SIV	8271,			217,		202,		A6,	.002626\$		"
SIM	8272,	3,	1,	227,	5,	232,	5,	A6,	.002626\$		"
SIV	8275,			242,		227,		A6,	.002626\$		"
SIM	8276,	3,	1,	702,	5,	707,	5,	A6,	.002626\$		"
SIV	8279,			717,		702,		A6,	.002626\$		"
SIM	8280,	3,	1,	727,	5,	732,	5,	A6,	.002626\$		"
SIV	8283,			742,		727,		A6,	.002626\$		"
SIM	8284,	3,	1,	206,	5,	211,	5,	A6,	.002858\$		CIRCUMF ON LENGTH
SIV	8287,			221,		206,		A6,	.002858\$		"
SIM	8288,	3,	1,	231,	5,	236,	5,	A6,	.002858\$		"
SIV	8291,			246,		231,		A6,	.002858\$		"
SIM	8700,	3,	1,	706,	5,	711,	5,	A6,	.002858\$		"
SIV	8703,			721,		706,		A6,	.002858\$		"
SIM	8704,	3,	1,	731,	5,	736,	5,	A6,	.002858\$		"
SIV	8707,			746,		731,		A6,	.002858\$		"
SIM	8708,	3,	1,	233,	5,	238,	5,	A6,	.000989\$		"
SIV	8711,			248,		233,		A6,	.000989\$		"
SIM	8712,	3,	1,	733,	5,	738,	5,	A6,	.000989\$		"
SIV	8715,			748,		733,		A6,	.000989\$		"
SIV	-8800,			602,		402,		A11,	4.398E-11	\$	PELLET 1/CLAD 1
SIM	-8801,	2,	1,	603,	1,	400,	4,	A11,	1.101E-11	\$	"
SIV	-8825,			627,		427,		A11,	4.398E-11	\$	PELLET 2/CLAD 2
SIM	-8826,	2,	1,	628,	1,	425,	4,	A11,	1.101E-11	\$	"
SIV	-8803,			402,		304,		A12,	5.176E-11	\$	CLAD 1/GIS
SIV	-8804,			400,		300,		A13,	1.288E-11	\$	"
SIV	-8828,			427,		329,		A12,	5.176E-11	\$	CLAD 2/GIS
SIV	-8829,			425,		325,		A13,	1.288E-11	\$	"
SIM	-8805,	2,	1,	404,	0,	500,	1,	A14,	0.644E-11	\$	CLAD 1/FM
SIM	-8830,	2,	1,	429,	0,	500,	1,	A14,	0.644E-11	\$	CLAD 2/FM
SIV	-8824,			502,		340,		A15,	1.949E-11	\$	FM/GIS
SIM	-8832,	4,	1,	300,	0,	702,	5,	A17,	5.615E-12	\$	GIS/SLEEVE
SIM	-8836,	4,	1,	325,	0,	727,	5,	A17,	5.615E-12	\$	"
SIM	-8840,	4,	1,	304,	0,	706,	5,	A16,	1.936E-11	\$	"
SIM	-8844,	4,	1,	329,	0,	731,	5,	A16,	1.936E-11	\$	"
SIM	-8848,	4,	1,	340,	0,	733,	5,	A16,	6.347E-12	\$	"
REM											
REM	**	GPS 1, SIDE "B" INTERIOR CONDUCTORS									**
REM											
SIV	1600,			1600,		1601,		A1,	1.033	\$	PELLET 3
SIV	1601,			1601,		1605,		A1,	2.221	\$	"
SIV	1602,			1605,		1602,		A1,	6.235	\$	"
SIM	1603,	2,	1,	1600,	0,	1603,	1,	A1,	.04736	\$	"
SIM	1605,	2,	1,	1601,	0,	1603,	1,	A1,	.04736	\$	"
SIM	1607,	2,	1,	1605,	0,	1603,	1,	A1,	.04736	\$	"
SIV	1625,			1625,		1626,		A1,	1.033	\$	PELLET 4
SIV	1626,			1626,		1630,		A1,	2.221	\$	"
SIV	1627,			1630,		1627,		A1,	6.235	\$	"
SIM	1628,	2,	1,	1625,	0,	1628,	1,	A1,	.04736	\$	"
SIM	1630,	2,	1,	1626,	0,	1628,	1,	A1,	.04736	\$	"
SIM	1632,	2,	1,	1630,	0,	1628,	1,	A1,	.04736	\$	"
SIM	1400,	2,	1,	1400,	4,	1401,	2,	A2,	.002899	\$	CLADING 3
SIM	1402,	2,	1,	1401,	2,	1402,	0,	A2,	.01301	\$	"
SIM	1425,	2,	1,	1425,	4,	1426,	2,	A2,	.002899	\$	CLADING 4
SIM	1427,	2,	1,	1426,	2,	1427,	0,	A2,	.01301	\$	"
SIV	1500,			1500,		1501,		A5,	.01773	\$	FLOATING MEM.
SIV	1501,			1501,		1502,		A5,	.08229	\$	"
SIM	1300,	2,	1,	1300,	25,	1302,	25,	A4,	.04604	\$	GIS
SIM	1302,	2,	1,	1302,	25,	1304,	25,	A3,	.09564	\$	"
SIM	1304,	2,	1,	1304,	25,	1340,	0,	A3,	.08398	\$	"
REM											
REM	\$ ** SLEEVE COND **										
SIM	1200,	4,	1,	1202,	5,	1702,	5,	A6,	.6875	\$	THRU THICKNESS

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SIM 1204, 4, 1,1227, 5,1727, 5, A6, .6875 $ "
SIM 1208, 4, 1,1206, 5,1706, 5, A6, 1.946 $ "
SIM 1212, 4, 1,1231, 5,1731, 5, A6, 1.946 $ "
SIM 1216, 4, 1,1233, 5,1733, 5, A6, .6733 $ "
SIM 1240, 4, 1,1206, 5,1233, 5, A6, .01040 $ ALONG LENGTH
SIM 1248, 4, 1,1231, 5,1233, 5, A6, .01040 $ "
SIM 1256, 4, 1,1706, 5,1733, 5, A6, .01040 $ "
SIM 1264, 4, 1,1731, 5,1733, 5, A6, .01040 $ "
SIM 1268, 3, 1,1202, 5,1207, 5, A6, .002626$ CIRCUMF ON ENDS
SIV 1271, 1217, 1202, A6, .002626$ "
SIM 1272, 3, 1,1227, 5,1232, 5, A6, .002626$ "
SIV 1275, 1242, 1227, A6, .002626$ "
SIM 1276, 3, 1,1702, 5,1707, 5, A6, .002626$ "
SIV 1279, 1717, 1702, A6, .002626$ "
SIM 1280, 3, 1,1727, 5,1732, 5, A6, .002626$ "
SIV 1283, 1742, 1727, A6, .002626$ "
SIM 1284, 3, 1,1206, 5,1211, 5, A6, .002858$ CIRCUMF ON LENGTH
SIV 1287, 1221, 1206, A6, .002858$ "
SIM 1288, 3, 1,1231, 5,1236, 5, A6, .002858$ "
SIV 1291, 1246, 1231, A6, .002858$ "
SIM 1700, 3, 1,1706, 5,1711, 5, A6, .002858$ "
SIV 1703, 1721, 1706, A6, .002858$ "
SIM 1704, 3, 1,1731, 5,1736, 5, A6, .002858$ "
SIV 1707, 1746, 1731, A6, .002858$ "
SIM 1708, 3, 1,1233, 5,1238, 5, A6, .000989$ "
SIV 1711, 1248, 1233, A6, .000989$ "
SIM 1712, 3, 1,1733, 5,1738, 5, A6, .000989$ "
SIV 1715, 1748, 1733, A6, .000989$ "
SIV -1800, 1602, 1402, A11, 4.398E-11 $ PELLET 3/CLAD 3
SIM -1801, 2, 1,1603, 1,1400, 4, A11, 1.101E-11 $ "
SIV -1825, 1627, 1427, A11, 4.398E-11 $ PELLET 4/CLAD 4
SIM -1826, 2, 1,1628, 1,1425, 4, A11, 1.101E-11 $ "
SIV -1803, 1402, 1304, A12, 5.176E-11 $ CLAD 3/GIS
SIV -1804, 1400, 1300, A13, 1.288E-11 $ "
SIV -1828, 1427, 1329, A12, 5.176E-11 $ CLAD 4/GIS
SIV -1829, 1425, 1325, A13, 1.288E-11 $ "
SIM -1805, 2, 1,1404, 0,1500, 1, A14, 0.644E-11 $ CLAD 3/FM
SIM -1830, 2, 1,1429, 0,1500, 1, A14, 0.644E-11 $ CLAD 4/FM
SIV -1824, 1502, 1340, A15, 1.949E-11 $ FM/GIS
SIM -1832, 4, 1,1300, 0,1702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -1836, 4, 1,1325, 0,1727, 5, A17, 5.615E-12 $ "
SIM -1840, 4, 1,1304, 0,1706, 5, A16, 1.936E-11 $ "
SIM -1844, 4, 1,1329, 0,1731, 5, A16, 1.936E-11 $ "
SIM -1848, 4, 1,1340, 0,1733, 5, A16, 6.347E-12 $ "
REM
REM
REM ** GPHS 2, SIDE "A" INTERIOR CONDUCTORS **
REM
SIV 2600, 2600, 2601, A1, 1.033 $ PELLET 1
SIV 2601, 2601, 2605, A1, 2.221 $ "
SIV 2602, 2605, 2602, A1, 6.235 $ "
SIM 2603, 2, 1,2600, 0,2603, 1, A1, .04736 $ "
SIM 2605, 2, 1,2601, 0,2603, 1, A1, .04736 $ "
SIM 2607, 2, 1,2605, 0,2603, 1, A1, .04736 $ "
SIV 2625, 2625, 2626, A1, 1.033 $ PELLET 2
SIV 2626, 2626, 2630, A1, 2.221 $ "
SIV 2627, 2630, 2627, A1, 6.235 $ "
SIM 2628, 2, 1,2625, 0,2628, 1, A1, .04736 $ "
SIM 2630, 2, 1,2626, 0,2628, 1, A1, .04736 $ "
SIM 2632, 2, 1,2630, 0,2628, 1, A1, .04736 $ "
SIM 2400, 2, 1,2400, 4,2401, 2, A2, .002899 $ CLADING 1
SIM 2402, 2, 1,2401, 2,2402, 0, A2, .01301 $ "
SIM 2425, 2, 1,2425, 4,2426, 2, A2, .002899 $ CLADING 2
SIM 2427, 2, 1,2426, 2,2427, 0, A2, .01301 $ "
SIV 2500, 2500, 2501, A5, .01773 $ FLOATING MEM.
SIV 2501, 2501, 2502, A5, .08229 $ "
SIM 2300, 2, 1,2300,25,2302,25, A4, .04604 $ GIS
SIM 2302, 2, 1,2302,25,2304,25, A3, .09564 $ "
SIM 2304, 2, 1,2304,25,2340, 0, A3, .08398 $ "

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REM                                     $ ** SLEEVE COND **
SIM 2200, 4, 1,2202, 5,2702, 5, A6, .6875 $ THRU THICKNESS
SIM 2204, 4, 1,2227, 5,2727, 5, A6, .6875 $ "
SIM 2208, 4, 1,2206, 5,2706, 5, A6, 1.946 $ "
SIM 2212, 4, 1,2231, 5,2731, 5, A6, 1.946 $ "
SIM 2216, 4, 1,2233, 5,2733, 5, A6, .6733 $ "
SIM 2240, 4, 1,2206, 5,2233, 5, A6, .01040 $ ALONG LENGTH
SIM 2248, 4, 1,2231, 5,2233, 5, A6, .01040 $ "
SIM 2256, 4, 1,2706, 5,2733, 5, A6, .01040 $ "
SIM 2264, 4, 1,2731, 5,2733, 5, A6, .01040 $ "
SIM 2268, 3, 1,2202, 5,2207, 5, A6, .002626$ CIRCUMF ON ENDS
SIV 2271, 2217, 2202, A6, .002626$ "
SIM 2272, 3, 1,2227, 5,2232, 5, A6, .002626$ "
SIV 2275, 2242, 2227, A6, .002626$ "
SIM 2276, 3, 1,2702, 5,2707, 5, A6, .002626$ "
SIV 2279, 2717, 2702, A6, .002626$ "
SIM 2280, 3, 1,2727, 5,2732, 5, A6, .002626$ "
SIV 2283, 2742, 2727, A6, .002626$ "
SIM 2284, 3, 1,2206, 5,2211, 5, A6, .002858$ CIRCUMF ON LENGTH
SIV 2287, 2221, 2206, A6, .002858$ "
SIM 2288, 3, 1,2231, 5,2236, 5, A6, .002858$ "
SIV 2291, 2246, 2231, A6, .002858$ "
SIM 2700, 3, 1,2706, 5,2711, 5, A6, .002858$ "
SIV 2703, 2721, 2706, A6, .002858$ "
SIM 2704, 3, 1,2731, 5,2736, 5, A6, .002858$ "
SIV 2707, 2746, 2731, A6, .002858$ "
SIM 2708, 3, 1,2233, 5,2238, 5, A6, .000989$ "
SIV 2711, 2248, 2233, A6, .000989$ "
SIM 2712, 3, 1,2733, 5,2738, 5, A6, .000989$ "
SIV 2715, 2748, 2733, A6, .000989$ "
SIV -2800, 2602, 2402, A11, 4.398E-11 $ PELLET 1/CLAD 1
SIM -2801, 2, 1,2603, 1,2400, 4, A11, 1.101E-11 $ "
SIV -2825, 2627, 2427, A11, 4.398E-11 $ PELLET 2/CLAD 2
SIM -2826, 2, 1,2628, 1,2425, 4, A11, 1.101E-11 $ "
SIV -2803, 2402, 2304, A12, 5.176E-11 $ CLAD 1/GIS
SIV -2804, 2400, 2300, A13, 1.288E-11 $ "
SIV -2828, 2427, 2329, A12, 5.176E-11 $ CLAD 2/GIS
SIV -2829, 2425, 2325, A13, 1.288E-11 $ "
SIM -2805, 2, 1,2404, 0,2500, 1, A14, 0.644E-11 $ CLAD 1/FM
SIM -2830, 2, 1,2429, 0,2500, 1, A14, 0.644E-11 $ CLAD 2/FM
SIV -2824, 2502, 2340, A15, 1.949E-11 $ FM/GIS
SIM -2832, 4, 1,2300, 0,2702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -2836, 4, 1,2325, 0,2727, 5, A17, 5.615E-12 $ "
SIM -2840, 4, 1,2304, 0,2706, 5, A16, 1.936E-11 $ "
SIM -2844, 4, 1,2329, 0,2731, 5, A16, 1.936E-11 $ "
SIM -2848, 4, 1,2340, 0,2733, 5, A16, 6.347E-12 $ "
REM
REM ** GPHS 2, SIDE "B" INTERIOR CONDUCTORS **
REM
SIV 3600, 3600, 3601, A1, 1.033 $ PELLET 3
SIV 3601, 3601, 3605, A1, 2.221 $ "
SIV 3602, 3605, 3602, A1, 6.235 $ "
SIM 3603, 2, 1,3600, 0,3603, 1, A1, .04736 $ "
SIM 3605, 2, 1,3601, 0,3603, 1, A1, .04736 $ "
SIM 3607, 2, 1,3605, 0,3603, 1, A1, .04736 $ "
SIV 3625, 3625, 3626, A1, 1.033 $ PELLET 4
SIV 3626, 3626, 3630, A1, 2.221 $ "
SIV 3627, 3630, 3627, A1, 6.235 $ "
SIM 3628, 2, 1,3625, 0,3628, 1, A1, .04736 $ "
SIM 3630, 2, 1,3626, 0,3628, 1, A1, .04736 $ "
SIM 3632, 2, 1,3630, 0,3628, 1, A1, .04736 $ "
SIM 3400, 2, 1,3400, 4,3401, 2, A2, .002899 $ CLADING 3
SIM 3402, 2, 1,3401, 2,3402, 0, A2, .01301 $ "
SIM 3425, 2, 1,3425, 4,3426, 2, A2, .002899 $ CLADING 4
SIM 3427, 2, 1,3426, 2,3427, 0, A2, .01301 $ "
SIV 3500, 3500, 3501, A5, .01773 $ FLOATING MEM.
SIV 3501, 3501, 3502, A5, .08229 $ "
SIM 3300, 2, 1,3300,25,3302,25, A4, .04604 $ GIS
SIM 3302, 2, 1,3302,25,3304,25, A3, .09564 $ "

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SIM 3304, 2, 1,3304,25,3340, 0, A3, .08398 $ "
REM $ ** SLEEVE COND **
SIM 3200, 4, 1,3202, 5,3702, 5, A6, .6875 $ THRU THICKNESS
SIM 3204, 4, 1,3227, 5,3727, 5, A6, .6875 $ "
SIM 3208, 4, 1,3206, 5,3706, 5, A6, 1.946 $ "
SIM 3212, 4, 1,3231, 5,3731, 5, A6, 1.946 $ "
SIM 3216, 4, 1,3233, 5,3733, 5, A6, .6733 $ "
SIM 3240, 4, 1,3206, 5,3233, 5, A6, .01040 $ ALONG LENGTH
SIM 3248, 4, 1,3231, 5,3233, 5, A6, .01040 $ "
SIM 3256, 4, 1,3706, 5,3733, 5, A6, .01040 $ "
SIM 3264, 4, 1,3731, 5,3733, 5, A6, .01040 $ "
SIM 3268, 3, 1,3202, 5,3207, 5, A6, .002626$ CIRCUMF ON ENDS
SIV 3271, 3217, 3202, A6, .002626$ "
SIM 3272, 3, 1,3227, 5,3232, 5, A6, .002626$ "
SIV 3275, 3242, 3227, A6, .002626$ "
SIM 3276, 3, 1,3702, 5,3707, 5, A6, .002626$ "
SIV 3279, 3717, 3702, A6, .002626$ "
SIM 3280, 3, 1,3727, 5,3732, 5, A6, .002626$ "
SIV 3283, 3742, 3727, A6, .002626$ "
SIM 3284, 3, 1,3206, 5,3211, 5, A6, .002858$ CIRCUMF ON LENGTH
SIV 3287, 3221, 3206, A6, .002858$ "
SIM 3288, 3, 1,3231, 5,3236, 5, A6, .002858$ "
SIV 3291, 3246, 3231, A6, .002858$ "
SIM 3700, 3, 1,3706, 5,3711, 5, A6, .002858$ "
SIV 3703, 3721, 3706, A6, .002858$ "
SIM 3704, 3, 1,3731, 5,3736, 5, A6, .002858$ "
SIV 3707, 3746, 3731, A6, .002858$ "
SIM 3708, 3, 1,3233, 5,3238, 5, A6, .000989$ "
SIV 3711, 3248, 3233, A6, .000989$ "
SIM 3712, 3, 1,3733, 5,3738, 5, A6, .000989$ "
SIV 3715, 3748, 3733, A6, .000989$ "
SIV -3800, 3602, 3402, A11, 4.398E-11 $ PELLET 3/CLAD 3
SIM -3801, 2, 1,3603, 1,3400, 4, A11, 1.101E-11 $ "
SIV -3825, 3627, 3427, A11, 4.398E-11 $ PELLET 4/CLAD 4
SIM -3826, 2, 1,3628, 1,3425, 4, A11, 1.101E-11 $ "
SIV -3803, 3402, 3304, A12, 5.176E-11 $ CLAD 3/GIS
SIV -3804, 3400, 3300, A13, 1.288E-11 $ "
SIV -3828, 3427, 3329, A12, 5.176E-11 $ CLAD 4/GIS
SIV -3829, 3425, 3325, A13, 1.288E-11 $ "
SIM -3805, 2, 1,3404, 0,3500, 1, A14, 0.644E-11 $ CLAD 3/FM
SIM -3830, 2, 1,3429, 0,3500, 1, A14, 0.644E-11 $ CLAD 4/FM
SIV -3824, 3502, 3340, A15, 1.949E-11 $ FM/GIS
SIM -3832, 4, 1,3300, 0,3702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -3836, 4, 1,3325, 0,3727, 5, A17, 5.615E-12 $ "
SIM -3840, 4, 1,3304, 0,3706, 5, A16, 1.936E-11 $ "
SIM -3844, 4, 1,3329, 0,3731, 5, A16, 1.936E-11 $ "
SIM -3848, 4, 1,3340, 0,3733, 5, A16, 6.347E-12 $ "
REM
REM
REM ** GPMS 3, SIDE "A" INTERIOR CONDUCTORS **
REM
SIV 4600, 4600, 4601, A1, 1.033 $ PELLET 1
SIV 4601, 4601, 4605, A1, 2.221 $ "
SIV 4602, 4605, 4602, A1, 6.235 $ "
SIM 4603, 2, 1,4600, 0,4603, 1, A1, .04736 $ "
SIM 4605, 2, 1,4601, 0,4603, 1, A1, .04736 $ "
SIM 4607, 2, 1,4605, 0,4603, 1, A1, .04736 $ "
SIV 4625, 4625, 4626, A1, 1.033 $ PELLET 2
SIV 4626, 4626, 4630, A1, 2.221 $ "
SIV 4627, 4630, 4627, A1, 6.235 $ "
SIM 4628, 2, 1,4625, 0,4628, 1, A1, .04736 $ "
SIM 4630, 2, 1,4626, 0,4628, 1, A1, .04736 $ "
SIM 4632, 2, 1,4630, 0,4628, 1, A1, .04736 $ "
SIM 4400, 2, 1,4400, 4,4401, 2, A2, .002899 $ CLADING 1
SIM 4402, 2, 1,4401, 2,4402, 0, A2, .01301 $ "
SIM 4425, 2, 1,4425, 4,4426, 2, A2, .002899 $ CLADING 2
SIM 4427, 2, 1,4426, 2,4427, 0, A2, .01301 $ "
SIV 4500, 4500, 4501, A5, .01773 $ FLOATING MEM.
SIV 4501, 4501, 4502, A5, .08229 $ "

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SIM 4300, 2, 1,4300,25,4302,25, A4, .04604 $ GIS
SIM 4302, 2, 1,4302,25,4304,25, A3, .09564 $ "
SIM 4304, 2, 1,4304,25,4340, 0, A3, .08398 $ "
REM $ ** SLEEVE COND **
SIM 4200, 4, 1,4202, 5,4702, 5, A6, .6875 $ THRU THICKNESS
SIM 4204, 4, 1,4227, 5,4727, 5, A6, .6875 $ "
SIM 4208, 4, 1,4206, 5,4706, 5, A6, 1.946 $ "
SIM 4212, 4, 1,4231, 5,4731, 5, A6, 1.946 $ "
SIM 4216, 4, 1,4233, 5,4733, 5, A6, .6733 $ "
SIM 4240, 4, 1,4206, 5,4233, 5, A6, .01040 $ ALONG LENGTH
SIM 4248, 4, 1,4231, 5,4233, 5, A6, .01040 $ "
SIM 4256, 4, 1,4706, 5,4733, 5, A6, .01040 $ "
SIM 4264, 4, 1,4731, 5,4733, 5, A6, .01040 $ "
SIM 4268, 3, 1,4202, 5,4207, 5, A6, .0026268 CIRCUMF ON ENDS
SIV 4271, 4217, 4202, A6, .0026268 "
SIM 4272, 3, 1,4227, 5,4232, 5, A6, .0026268 "
SIV 4275, 4242, 4227, A6, .0026268 "
SIM 4276, 3, 1,4702, 5,4707, 5, A6, .0026268 "
SIV 4279, 4717, 4702, A6, .0026268 "
SIM 4280, 3, 1,4727, 5,4732, 5, A6, .0026268 "
SIV 4283, 4742, 4727, A6, .0026268 "
SIM 4284, 3, 1,4206, 5,4211, 5, A6, .0028588 CIRCUMF ON LENGTH
SIV 4287, 4221, 4206, A6, .0028588 "
SIM 4288, 3, 1,4231, 5,4236, 5, A6, .0028588 "
SIV 4291, 4246, 4231, A6, .0028588 "
SIM 4700, 3, 1,4706, 5,4711, 5, A6, .0028588 "
SIV 4703, 4721, 4706, A6, .0028588 "
SIM 4704, 3, 1,4731, 5,4736, 5, A6, .0028588 "
SIV 4707, 4746, 4731, A6, .0028588 "
SIM 4708, 3, 1,4233, 5,4238, 5, A6, .0009898 "
SIV 4711, 4248, 4233, A6, .0009898 "
SIM 4712, 3, 1,4733, 5,4738, 5, A6, .0009898 "
SIV 4715, 4748, 4733, A6, .0009898 "
SIV -4800, 4602, 4402, A11, 4.398E-11 $ PELLET 1/CLAD 1
SIM -4801, 2, 1,4603, 1,4400, 4, A11, 1.101E-11 $ "
SIV -4825, 4627, 4427, A11, 4.398E-11 $ PELLET 2/CLAD 2
SIM -4826, 2, 1,4628, 1,4425, 4, A11, 1.101E-11 $ "
SIV -4803, 4402, 4304, A12, 5.176E-11 $ CLAD 1/GIS
SIV -4804, 4400, 4300, A13, 1.288E-11 $ "
SIV -4828, 4427, 4329, A12, 5.176E-11 $ CLAD 2/GIS
SIV -4829, 4425, 4325, A13, 1.288E-11 $ "
SIM -4805, 2, 1,4404, 0,4500, 1, A14, 0.644E-11 $ CLAD 1/FM
SIM -4830, 2, 1,4429, 0,4500, 1, A14, 0.644E-11 $ CLAD 2/FM
SIV -4824, 4502, 4340, A15, 1.949E-11 $ FM/GIS
SIM -4832, 4, 1,4300, 0,4702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -4836, 4, 1,4325, 0,4727, 5, A17, 5.615E-12 $ "
SIM -4840, 4, 1,4304, 0,4706, 5, A16, 1.936E-11 $ "
SIM -4844, 4, 1,4329, 0,4731, 5, A16, 1.936E-11 $ "
SIM -4848, 4, 1,4340, 0,4733, 5, A16, 6.347E-12 $ "
REM
REM ** GPHS 3, SIDE "B" INTERIOR CONDUCTORS **
REM
SIV 5600, 5600, 5601, A1, 1.033 $ PELLET 3
SIV 5601, 5601, 5605, A1, 2.221 $ "
SIV 5602, 5605, 5602, A1, 6.235 $ "
SIM 5603, 2, 1,5600, 0,5603, 1, A1, .04736 $ "
SIM 5605, 2, 1,5601, 0,5603, 1, A1, .04736 $ "
SIM 5607, 2, 1,5605, 0,5603, 1, A1, .04736 $ "
SIV 5625, 5625, 5626, A1, 1.033 $ PELLET 4
SIV 5626, 5626, 5630, A1, 2.221 $ "
SIV 5627, 5630, 5627, A1, 6.235 $ "
SIM 5628, 2, 1,5625, 0,5628, 1, A1, .04736 $ "
SIM 5630, 2, 1,5626, 0,5628, 1, A1, .04736 $ "
SIM 5632, 2, 1,5630, 0,5628, 1, A1, .04736 $ "
SIM 5400, 2, 1,5400, 4,5401, 2, A2, .002899 $ CLADING 3
SIM 5402, 2, 1,5401, 2,5402, 0, A2, .01301 $ "
SIM 5425, 2, 1,5425, 4,5426, 2, A2, .002899 $ CLADING 4
SIM 5427, 2, 1,5426, 2,5427, 0, A2, .01301 $ "
SIV 5500, 5500, 5501, A5, .01773 $ FLOATING MEM.

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SIV	5501,	5501,	5502,	A5,	.08229	\$ "
SIM	5300, 2,	1,5300,25,	5302,25,	A4,	.04604	\$ GIS
SIM	5302, 2,	1,5302,25,	5304,25,	A3,	.09564	\$ "
SIM	5304, 2,	1,5304,25,	5340, 0,	A3,	.08398	\$ "
REM						\$ ** SLEEVE COND **
SIM	5200, 4,	1,5202,	5,5702,	5,	A6,	.6875 \$ THRU THICKNESS
SIM	5204, 4,	1,5227,	5,5727,	5,	A6,	.6875 \$ "
SIM	5208, 4,	1,5206,	5,5706,	5,	A6,	1.946 \$ "
SIM	5212, 4,	1,5231,	5,5731,	5,	A6,	1.946 \$ "
SIM	5216, 4,	1,5233,	5,5733,	5,	A6,	.6733 \$ "
SIM	5240, 4,	1,5206,	5,5233,	5,	A6,	.01040 \$ ALONG LENGTH
SIM	5248, 4,	1,5231,	5,5233,	5,	A6,	.01040 \$ "
SIM	5256, 4,	1,5706,	5,5733,	5,	A6,	.01040 \$ "
SIM	5264, 4,	1,5731,	5,5733,	5,	A6,	.01040 \$ "
SIM	5268, 3,	1,5202,	5,5207,	5,	A6,	.002626\$ CIRCUMF ON ENDS
SIV	5271,	5217,	5202,	A6,	.002626\$ "	
SIM	5272, 3,	1,5227,	5,5232,	5,	A6,	.002626\$ "
SIV	5275,	5242,	5227,	A6,	.002626\$ "	
SIM	5276, 3,	1,5702,	5,5707,	5,	A6,	.002626\$ "
SIV	5279,	5717,	5702,	A6,	.002626\$ "	
SIM	5280, 3,	1,5727,	5,5732,	5,	A6,	.002626\$ "
SIV	5283,	5742,	5727,	A6,	.002626\$ "	
SIM	5284, 3,	1,5206,	5,5211,	5,	A6,	.002858\$ CIRCUMF ON LENGTH
SIV	5287,	5221,	5206,	A6,	.002858\$ "	
SIM	5288, 3,	1,5231,	5,5236,	5,	A6,	.002858\$ "
SIV	5291,	5246,	5231,	A6,	.002858\$ "	
SIM	5700, 3,	1,5706,	5,5711,	5,	A6,	.002858\$ "
SIV	5703,	5721,	5706,	A6,	.002858\$ "	
SIM	5704, 3,	1,5731,	5,5736,	5,	A6,	.002858\$ "
SIV	5707,	5746,	5731,	A6,	.002858\$ "	
SIM	5708, 3,	1,5233,	5,5238,	5,	A6,	.000989\$ "
SIV	5711,	5248,	5233,	A6,	.000989\$ "	
SIM	5712, 3,	1,5733,	5,5738,	5,	A6,	.000989\$ "
SIV	5715,	5748,	5733,	A6,	.000989\$ "	
SIV	-5800,	5602,	5402,	A11,	4.398E-11	\$ PELLET 3/CLAD 3
SIM	-5801, 2,	1,5603,	1,5400,	4,	A11,	1.101E-11 \$ "
SIV	-5825,	5627,	5427,	A11,	4.398E-11	\$ PELLET 4/CLAD 4
SIM	-5826, 2,	1,5628,	1,5425,	4,	A11,	1.101E-11 \$ "
SIV	-5803,	5402,	5304,	A12,	5.176E-11	\$ CLAD 3/GIS
SIV	-5804,	5400,	5300,	A13,	1.288E-11	\$ "
SIV	-5828,	5427,	5329,	A12,	5.176E-11	\$ CLAD 4/GIS
SIV	-5829,	5425,	5325,	A13,	1.288E-11	\$ "
SIM	-5805, 2,	1,5404,	0,5500,	1,	A14,	0.644E-11 \$ CLAD 3/FM
SIM	-5830, 2,	1,5429,	0,5500,	1,	A14,	0.644E-11 \$ CLAD 4/FM
SIV	-5824,	5502,	5340,	A15,	1.949E-11	\$ FM/GIS
SIM	-5832, 4,	1,5300,	0,5702,	5,	A17,	5.615E-12 \$ GIS/SLEEVE
SIM	-5836, 4,	1,5325,	0,5727,	5,	A17,	5.615E-12 \$ "
SIM	-5840, 4,	1,5304,	0,5706,	5,	A16,	1.936E-11 \$ "
SIM	-5844, 4,	1,5329,	0,5731,	5,	A16,	1.936E-11 \$ "
SIM	-5848, 4,	1,5340,	0,5733,	5,	A16,	6.347E-12 \$ "
REM						
REM						
REM	**	GPS 4,	SIDE "A"	INTERIOR CONDUCTORS	**	
REM						
SIV	6600,	6600,	6601,	A1,	1.033	\$ PELLET 1
SIV	6601,	6601,	6605,	A1,	2.221	\$ "
SIV	6602,	6605,	6602,	A1,	6.235	\$ "
SIM	6603, 2,	1,6600,	0,6603,	1,	A1,	.04736 \$ "
SIM	6605, 2,	1,6601,	0,6603,	1,	A1,	.04736 \$ "
SIM	6607, 2,	1,6605,	0,6603,	1,	A1,	.04736 \$ "
SIV	6625,	6625,	6626,	A1,	1.033	\$ PELLET 2
SIV	6626,	6626,	6630,	A1,	2.221	\$ "
SIV	6627,	6630,	6627,	A1,	6.235	\$ "
SIM	6628, 2,	1,6625,	0,6628,	1,	A1,	.04736 \$ "
SIM	6630, 2,	1,6626,	0,6628,	1,	A1,	.04736 \$ "
SIM	6632, 2,	1,6630,	0,6628,	1,	A1,	.04736 \$ "
SIM	6400, 2,	1,6400,	4,6401,	2,	A2,	.002899 \$ CLADING 1
SIM	6402, 2,	1,6401,	2,6402,	0,	A2,	.01301 \$ "
SIM	6425, 2,	1,6425,	4,6426,	2,	A2,	.002899 \$ CLADING 2

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SIM 6427, 2, 1,6426, 2,6427, 0, A2, .01301 $ "
SIV 6500, 6500, 6501, A5, .01773 $ FLOATING MEM.
SIV 6501, 6501, 6502, A5, .08229 $ "
SIM 6300, 2, 1,6300,25,6302,25, A4, .04604 $ GIS
SIM 6302, 2, 1,6302,25,6304,25, A3, .09564 $ "
SIM 6304, 2, 1,6304,25,6340, 0, A3, .08398 $ "
REM $ ** SLEEVE COND **
SIM 6200, 4, 1,6202, 5,6702, 5, A6, .6875 $ THRU THICKNESS
SIM 6204, 4, 1,6227, 5,6727, 5, A6, .6875 $ "
SIM 6208, 4, 1,6206, 5,6706, 5, A6, 1.946 $ "
SIM 6212, 4, 1,6231, 5,6731, 5, A6, 1.946 $ "
SIM 6216, 4, 1,6233, 5,6733, 5, A6, .6733 $ "
SIM 6240, 4, 1,6206, 5,6233, 5, A6, .01040 $ ALONG LENGTH
SIM 6248, 4, 1,6231, 5,6233, 5, A6, .01040 $ "
SIM 6256, 4, 1,6706, 5,6733, 5, A6, .01040 $ "
SIM 6264, 4, 1,6731, 5,6733, 5, A6, .01040 $ "
SIM 6268, 3, 1,6202, 5,6207, 5, A6, .0026268 CIRCUMF ON ENDS
SIV 6271, 6217, 6202, A6, .0026268 "
SIM 6272, 3, 1,6227, 5,6232, 5, A6, .0026268 "
SIV 6275, 6242, 6227, A6, .0026268 "
SIM 6276, 3, 1,6702, 5,6707, 5, A6, .0026268 "
SIV 6279, 6717, 6702, A6, .0026268 "
SIM 6280, 3, 1,6727, 5,6732, 5, A6, .0026268 "
SIV 6283, 6742, 6727, A6, .0026268 "
SIM 6284, 3, 1,6206, 5,6211, 5, A6, .0028588 CIRCUMF ON LENGTH
SIV 6287, 6221, 6206, A6, .0028588 "
SIM 6288, 3, 1,6231, 5,6236, 5, A6, .0028588 "
SIV 6291, 6246, 6231, A6, .0028588 "
SIM 6700, 3, 1,6706, 5,6711, 5, A6, .0028588 "
SIV 6703, 6721, 6706, A6, .0028588 "
SIM 6704, 3, 1,6731, 5,6736, 5, A6, .0028588 "
SIV 6707, 6746, 6731, A6, .0028588 "
SIM 6708, 3, 1,6233, 5,6238, 5, A6, .0009898 "
SIV 6711, 6248, 6233, A6, .0009898 "
SIM 6712, 3, 1,6733, 5,6738, 5, A6, .0009898 "
SIV 6715, 6748, 6733, A6, .0009898 "
SIV -6800, 6602, 6402, A11, 4.398E-11 $ PELLET 1/CLAD 1
SIM -6801, 2, 1,6603, 1,6400, 4, A11, 1.101E-11 $ "
SIV -6825, 6627, 6427, A11, 4.398E-11 $ PELLET 2/CLAD 2
SIM -6826, 2, 1,6628, 1,6425, 4, A11, 1.101E-11 $ "
SIV -6803, 6402, 6304, A12, 5.176E-11 $ CLAD 1/GIS
SIV -6804, 6400, 6300, A13, 1.288E-11 $ "
SIV -6828, 6427, 6329, A12, 5.176E-11 $ CLAD 2/GIS
SIV -6829, 6425, 6325, A13, 1.288E-11 $ "
SIM -6805, 2, 1,6404, 0,6500, 1, A14, 0.644E-11 $ CLAD 1/FM
SIM -6830, 2, 1,6429, 0,6500, 1, A14, 0.644E-11 $ CLAD 2/FM
SIV -6824, 6502, 6340, A15, 1.949E-11 $ FM/GIS
SIM -6832, 4, 1,6300, 0,6702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -6836, 4, 1,6325, 0,6727, 5, A17, 5.615E-12 $ "
SIM -6840, 4, 1,6304, 0,6706, 5, A16, 1.936E-11 $ "
SIM -6844, 4, 1,6329, 0,6731, 5, A16, 1.936E-11 $ "
SIM -6848, 4, 1,6340, 0,6733, 5, A16, 6.347E-12 $ "
REM
REM ** GPHS 4, SIDE "B" INTERIOR CONDUCTORS **
REM
SIV 7600, 7600, 7601, A1, 1.033 $ PELLET 3
SIV 7601, 7601, 7605, A1, 2.221 $ "
SIV 7602, 7605, 7602, A1, 6.235 $ "
SIM 7603, 2, 1,7600, 0,7603, 1, A1, .04736 $ "
SIM 7605, 2, 1,7601, 0,7603, 1, A1, .04736 $ "
SIM 7607, 2, 1,7605, 0,7603, 1, A1, .04736 $ "
SIV 7625, 7625, 7626, A1, 1.033 $ PELLET 4
SIV 7626, 7626, 7630, A1, 2.221 $ "
SIV 7627, 7630, 7627, A1, 6.235 $ "
SIM 7628, 2, 1,7625, 0,7628, 1, A1, .04736 $ "
SIM 7630, 2, 1,7626, 0,7628, 1, A1, .04736 $ "
SIM 7632, 2, 1,7630, 0,7628, 1, A1, .04736 $ "
SIM 7400, 2, 1,7400, 4,7401, 2, A2, .002899 $ CLADING 3
SIM 7402, 2, 1,7401, 2,7402, 0, A2, .01301 $ "

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SIM 7425, 2, 1, 7425, 4, 7426, 2, A2, .002899 $ CLADING 4
SIM 7427, 2, 1, 7426, 2, 7427, 0, A2, .01301 $ "
SIV 7500, 7500, 7501, A5, .01773 $ FLOATING MEM.
SIV 7501, 7501, 7502, A5, .08229 $ "
SIM 7300, 2, 1, 7300, 25, 7302, 25, A4, .04604 $ GIS
SIM 7302, 2, 1, 7302, 25, 7304, 25, A3, .09564 $ "
SIM 7304, 2, 1, 7304, 25, 7340, 0, A3, .08398 $ "
REM $ ** SLEEVE COND **
SIM 7200, 4, 1, 7202, 5, 7702, 5, A6, .6875 $ THRU THICKNESS
SIM 7204, 4, 1, 7227, 5, 7727, 5, A6, .6875 $ "
SIM 7208, 4, 1, 7206, 5, 7706, 5, A6, 1.946 $ "
SIM 7212, 4, 1, 7231, 5, 7731, 5, A6, 1.946 $ "
SIM 7216, 4, 1, 7233, 5, 7733, 5, A6, .6733 $ "
SIM 7240, 4, 1, 7206, 5, 7233, 5, A6, .01040 $ ALONG LENGTH
SIM 7248, 4, 1, 7231, 5, 7233, 5, A6, .01040 $ "
SIM 7256, 4, 1, 7706, 5, 7733, 5, A6, .01040 $ "
SIM 7264, 4, 1, 7731, 5, 7733, 5, A6, .01040 $ "
SIM 7268, 3, 1, 7202, 5, 7207, 5, A6, .002626 $ CIRCUMF ON ENDS
SIV 7271, 7217, 7202, A6, .002626 $ "
SIM 7272, 3, 1, 7227, 5, 7232, 5, A6, .002626 $ "
SIV 7275, 7242, 7227, A6, .002626 $ "
SIM 7276, 3, 1, 7702, 5, 7707, 5, A6, .002626 $ "
SIV 7279, 7717, 7702, A6, .002626 $ "
SIM 7280, 3, 1, 7727, 5, 7732, 5, A6, .002626 $ "
SIV 7283, 7742, 7727, A6, .002626 $ "
SIM 7284, 3, 1, 7206, 5, 7211, 5, A6, .002858 $ CIRCUMF ON LENGTH
SIV 7287, 7221, 7206, A6, .002858 $ "
SIM 7288, 3, 1, 7231, 5, 7236, 5, A6, .002858 $ "
SIV 7291, 7246, 7231, A6, .002858 $ "
SIM 7700, 3, 1, 7706, 5, 7711, 5, A6, .002858 $ "
SIV 7703, 7721, 7706, A6, .002858 $ "
SIM 7704, 3, 1, 7731, 5, 7736, 5, A6, .002858 $ "
SIV 7707, 7746, 7731, A6, .002858 $ "
SIM 7708, 3, 1, 7233, 5, 7238, 5, A6, .000989 $ "
SIV 7711, 7248, 7233, A6, .000989 $ "
SIM 7712, 3, 1, 7733, 5, 7738, 5, A6, .000989 $ "
SIV 7715, 7748, 7733, A6, .000989 $ "
SIV -7800, 7602, 7402, A11, 4.398E-11 $ PELLET 3/CLAD 3
SIM -7801, 2, 1, 7603, 1, 7400, 4, A11, 1.101E-11 $ "
SIV -7825, 7627, 7427, A11, 4.398E-11 $ PELLET 4/CLAD 4
SIM -7826, 2, 1, 7628, 1, 7425, 4, A11, 1.101E-11 $ "
SIV -7803, 7402, 7304, A12, 5.176E-11 $ CLAD 3/GIS
SIV -7804, 7400, 7300, A13, 1.288E-11 $ "
SIV -7828, 7427, 7329, A12, 5.176E-11 $ CLAD 4/GIS
SIV -7829, 7425, 7325, A13, 1.288E-11 $ "
SIM -7805, 2, 1, 7404, 0, 7500, 1, A14, 0.644E-11 $ CLAD 3/FM
SIM -7830, 2, 1, 7429, 0, 7500, 1, A14, 0.644E-11 $ CLAD 4/FM
SIV -7824, 7502, 7340, A15, 1.949E-11 $ FM/GIS
SIM -7832, 4, 1, 7300, 0, 7702, 5, A17, 5.615E-12 $ GIS/SLEEVE
SIM -7836, 4, 1, 7325, 0, 7727, 5, A17, 5.615E-12 $ "
SIM -7840, 4, 1, 7304, 0, 7706, 5, A16, 1.936E-11 $ "
SIM -7844, 4, 1, 7329, 0, 7731, 5, A16, 1.936E-11 $ "
SIM -7848, 4, 1, 7340, 0, 7733, 5, A16, 6.347E-12 $ "
REM
REM *****
REM RADIATION CONDUCTANCES BETWEEN SLEEVES
REM AND AEROSHELLS INSIDE GPHS BLOCKS
REM *****
REM
REM ** GPHS 1, RADK'S [SLEEVES <--> AEROSHELL] **
REM
SIM -8901, 2, 1, 206, 10, 101, 2, A18, 2.142E-11 $ CYL/A.S.
SIM -8903, 2, 1, 1206, 10, 101, 2, A18, 2.142E-11 $ "
SIM -8905, 2, 1, 221, 990, 102, 2, A19, 2.142E-11 $ "
SIM -8907, 2, 1, 231, 10, 101, 2, A18, 2.142E-11 $ "
SIM -8909, 2, 1, 1231, 10, 101, 2, A18, 2.142E-11 $ "
SIM -8911, 2, 1, 246, 990, 102, 2, A19, 2.142E-11 $ "
SIM -8913, 2, 1, 233, 10, 101, 2, A18, 7.022E-12 $ "
SIM -8915, 2, 1, 1233, 10, 101, 2, A18, 7.022E-12 $ "

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SIM -8917, 2, 1, 248, 990, 102, 2, A19, 7.022E-12 $ "
SIM -8919, 4, 1, 202, 5, 100, 0, A19, 6.873E-12 $ END CAPS/A.S.
SIM -8923, 4, 1, 1202, 5, 100, 0, A19, 6.873E-12 $ "
SIM -8927, 4, 1, 227, 5, 105, 0, A19, 6.873E-12 $ "
SIM -8931, 4, 1, 1227, 5, 105, 0, A19, 6.873E-12 $ "
SIM -8935, 238, 1248, 4.682E-12 $ SLV A/SLV B
GEN -8936, 2, 1, 211, 25, 1221, 27, 1.428E-11 $ "
REM
REM ** GPHS 2, RADK'S [SLEEVES <--> AEROSHELL] **
REM
SIM -2901, 2, 1, 2206, 10, 2101, 2, A18, 2.142E-11 $ CYL/A.S.
SIM -2903, 2, 1, 3206, 10, 2101, 2, A18, 2.142E-11 $ "
SIM -2905, 2, 1, 2221, 990, 2102, 2, A19, 2.142E-11 $ "
SIM -2907, 2, 1, 2231, 10, 2101, 2, A18, 2.142E-11 $ "
SIM -2909, 2, 1, 3231, 10, 2101, 2, A18, 2.142E-11 $ "
SIM -2911, 2, 1, 2246, 990, 2102, 2, A19, 2.142E-11 $ "
SIM -2913, 2, 1, 2233, 10, 2101, 2, A18, 7.022E-12 $ "
SIM -2915, 2, 1, 3233, 10, 2101, 2, A18, 7.022E-12 $ "
SIM -2917, 2, 1, 2248, 990, 2102, 2, A19, 7.022E-12 $ "
SIM -2919, 4, 1, 2202, 5, 2100, 0, A19, 6.873E-12 $ END CAPS/A.S.
SIM -2923, 4, 1, 3202, 5, 2100, 0, A19, 6.873E-12 $ "
SIM -2927, 4, 1, 2227, 5, 2105, 0, A19, 6.873E-12 $ "
SIM -2931, 4, 1, 3227, 5, 2105, 0, A19, 6.873E-12 $ "
SIM -2935, 2238, 3248, 4.682E-12 $ SLV A/SLV B
GEN -2936, 2, 1, 2211, 25, 3221, 27, 1.428E-11 $ "
REM
REM ** GPHS 3, RADK'S [SLEEVES <--> AEROSHELL] **
REM
SIM -4901, 2, 1, 4206, 10, 4101, 2, A18, 2.142E-11 $ CYL/A.S.
SIM -4903, 2, 1, 5206, 10, 4101, 2, A18, 2.142E-11 $ "
SIM -4905, 2, 1, 4221, 990, 4102, 2, A19, 2.142E-11 $ "
SIM -4907, 2, 1, 4231, 10, 4101, 2, A18, 2.142E-11 $ "
SIM -4909, 2, 1, 5231, 10, 4101, 2, A18, 2.142E-11 $ "
SIM -4911, 2, 1, 4246, 990, 4102, 2, A19, 2.142E-11 $ "
SIM -4913, 2, 1, 4233, 10, 4101, 2, A18, 7.022E-12 $ "
SIM -4915, 2, 1, 5233, 10, 4101, 2, A18, 7.022E-12 $ "
SIM -4917, 2, 1, 4248, 990, 4102, 2, A19, 7.022E-12 $ "
SIM -4919, 4, 1, 4202, 5, 4100, 0, A19, 6.873E-12 $ END CAPS/A.S.
SIM -4923, 4, 1, 5202, 5, 4100, 0, A19, 6.873E-12 $ "
SIM -4927, 4, 1, 4227, 5, 4105, 0, A19, 6.873E-12 $ "
SIM -4931, 4, 1, 5227, 5, 4105, 0, A19, 6.873E-12 $ "
SIM -4935, 4238, 5248, 4.682E-12 $ SLV A/SLV B
GEN -4936, 2, 1, 4211, 25, 5221, 27, 1.428E-11 $ "
REM
REM ** GPHS 4, RADK'S [SLEEVES <--> AEROSHELL] **
REM
SIM -6901, 2, 1, 6206, 10, 6101, 2, A18, 2.142E-11 $ CYL/A.S.
SIM -6903, 2, 1, 7206, 10, 6101, 2, A18, 2.142E-11 $ "
SIM -6905, 2, 1, 6221, 990, 6102, 2, A19, 2.142E-11 $ "
SIM -6907, 2, 1, 6231, 10, 6101, 2, A18, 2.142E-11 $ "
SIM -6909, 2, 1, 7231, 10, 6101, 2, A18, 2.142E-11 $ "
SIM -6911, 2, 1, 6246, 990, 6102, 2, A19, 2.142E-11 $ "
SIM -6913, 2, 1, 6233, 10, 6101, 2, A18, 7.022E-12 $ "
SIM -6915, 2, 1, 7233, 10, 6101, 2, A18, 7.022E-12 $ "
SIM -6917, 2, 1, 6248, 990, 6102, 2, A19, 7.022E-12 $ "
SIM -6919, 4, 1, 6202, 5, 6100, 0, A19, 6.873E-12 $ END CAPS/A.S.
SIM -6923, 4, 1, 7202, 5, 6100, 0, A19, 6.873E-12 $ "
SIM -6927, 4, 1, 6227, 5, 6105, 0, A19, 6.873E-12 $ "
SIM -6931, 4, 1, 7227, 5, 6105, 0, A19, 6.873E-12 $ "
SIM -6935, 6238, 7248, 4.682E-12 $ SLV A/SLV B
GEN -6936, 2, 1, 6211, 25, 7221, 27, 1.428E-11 $ "
REM
REM *****
REM RADKS FROM TRASYS
REM *****
REM
- 1, 10100, 10200, 1.44871E-13$
- 2, 10100, 100, 8.78349E-13$

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-	3,	10100,	101,	2.92091E-11\$
-	4,	10100,	102,	9.46276E-13\$
-	5,	10100,	103,	1.70504E-12\$
-	6,	10100,	104,	9.79457E-13\$
-	7,	10100,	105,	3.87351E-12\$
-	8,	10100,	2100,	8.78348E-13\$
-	9,	10100,	2101,	2.92048E-11\$
-	10,	10100,	2102,	9.24256E-13\$
-	11,	10100,	2103,	1.72961E-12\$
-	12,	10100,	2104,	9.54927E-13\$
-	13,	10100,	2105,	4.19903E-12\$
-	14,	10100,	4100,	8.78348E-13\$
-	15,	10100,	4101,	2.92049E-11\$
-	16,	10100,	4102,	9.54944E-13\$
-	17,	10100,	4103,	1.72960E-12\$
-	18,	10100,	4104,	9.24261E-13\$
-	19,	10100,	4105,	4.19903E-12\$
-	20,	10100,	6100,	8.78348E-13\$
-	21,	10100,	6101,	2.92090E-11\$
-	22,	10100,	6102,	9.79479E-13\$
-	23,	10100,	6103,	1.70498E-12\$
-	24,	10100,	6104,	9.46260E-13\$
-	25,	10100,	6105,	3.87351E-12\$
-	26,	10100,	10400,	2.37619E-12\$
-	27,	10100,	10500,	4.89943E-12\$
-	28,	10100,	10600,	1.15739E-12\$
-	29,	10200,	100,	4.99907E-13\$
-	30,	10200,	101,	5.91492E-13\$
-	31,	10200,	102,	8.60044E-14\$
-	32,	10200,	103,	1.27886E-13\$
-	33,	10200,	104,	9.21329E-14\$
-	34,	10200,	105,	3.96286E-14\$
-	35,	10200,	2100,	4.99907E-13\$
-	36,	10200,	2101,	5.84488E-13\$
-	37,	10200,	2102,	8.77847E-14\$
-	38,	10200,	2103,	1.43460E-13\$
-	39,	10200,	2104,	8.66905E-14\$
-	40,	10200,	2105,	3.96937E-14\$
-	41,	10200,	4100,	4.99907E-13\$
-	42,	10200,	4101,	5.84488E-13\$
-	43,	10200,	4102,	8.66906E-14\$
-	44,	10200,	4103,	1.43460E-13\$
-	45,	10200,	4104,	8.77848E-14\$
-	46,	10200,	4105,	3.96937E-14\$
-	47,	10200,	6100,	4.99907E-13\$
-	48,	10200,	6101,	5.91492E-13\$
-	49,	10200,	6102,	9.21349E-14\$
-	50,	10200,	6103,	1.27881E-13\$
-	51,	10200,	6104,	8.60044E-14\$
-	52,	10200,	6105,	3.96287E-14\$
-	53,	10200,	10400,	1.88480E-13\$
-	54,	10200,	10500,	5.01245E-14\$
-	55,	10200,	10600,	6.58720E-13\$
-	56,	100,	101,	2.62294E-12\$
-	57,	100,	102,	1.07898E-12\$
-	58,	100,	103,	1.60315E-12\$
-	59,	100,	104,	1.15642E-12\$
-	60,	100,	105,	4.44002E-13\$
-	61,	100,	2100,	6.33911E-12\$
-	62,	100,	2101,	2.53408E-12\$
-	63,	100,	2102,	1.10186E-12\$
-	64,	100,	2103,	1.80075E-12\$
-	65,	100,	2104,	1.08759E-12\$
-	66,	100,	2105,	4.44396E-13\$
-	67,	100,	4100,	6.33911E-12\$
-	68,	100,	4101,	2.53408E-12\$
-	69,	100,	4102,	1.08759E-12\$
-	70,	100,	4103,	1.80074E-12\$
-	71,	100,	4104,	1.10187E-12\$

-	72,	100,	4105,	4.44396E-13\$
-	73,	100,	6100,	6.33910E-12\$
-	74,	100,	6101,	2.62294E-12\$
-	75,	100,	6102,	1.15644E-12\$
-	76,	100,	6103,	1.60309E-12\$
-	77,	100,	6104,	1.07898E-12\$
-	78,	100,	6105,	4.44002E-13\$
-	79,	100,	10400,	2.36490E-12\$
-	80,	100,	10500,	5.61598E-13\$
-	81,	100,	10600,	8.35294E-12\$
-	82,	101,	102,	7.71614E-13\$
-	83,	101,	103,	1.21375E-12\$
-	84,	101,	104,	8.11775E-13\$
-	85,	101,	105,	1.94296E-12\$
-	86,	101,	2100,	2.62294E-12\$
-	87,	101,	2101,	2.12622E-11\$
-	88,	101,	2102,	8.69555E-13\$
-	89,	101,	2103,	1.29203E-12\$
-	90,	101,	2104,	7.71034E-13\$
-	91,	101,	2105,	1.95608E-12\$
-	92,	101,	4100,	2.62294E-12\$
-	93,	101,	4101,	1.05777E-11\$
-	94,	101,	4102,	7.73057E-13\$
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-	96,	101,	4104,	7.67056E-13\$
-	97,	101,	4105,	1.95608E-12\$
-	98,	101,	6100,	2.62294E-12\$
-	99,	101,	6101,	2.12967E-11\$
-	100,	101,	6102,	8.04933E-13\$
-	101,	101,	6103,	1.21370E-12\$
-	102,	101,	6104,	8.68828E-13\$
-	103,	101,	6105,	1.94296E-12\$
-	104,	101,	10400,	1.72480E-12\$
-	105,	101,	10500,	2.45757E-12\$
-	106,	101,	10600,	3.45621E-12\$
-	107,	102,	103,	4.21773E-12\$
-	108,	102,	104,	1.77331E-12\$
-	109,	102,	105,	1.22987E-12\$
-	110,	102,	2100,	1.07898E-12\$
-	111,	102,	2101,	7.54844E-13\$
-	112,	102,	2102,	1.62716E-12\$
-	113,	102,	2103,	4.30734E-12\$
-	114,	102,	2104,	1.71745E-12\$
-	115,	102,	2105,	1.23029E-12\$
-	116,	102,	4100,	1.07898E-12\$
-	117,	102,	4101,	7.56864E-13\$
-	118,	102,	4102,	1.71741E-12\$
-	119,	102,	4103,	4.30733E-12\$
-	120,	102,	4104,	1.62728E-12\$
-	121,	102,	4105,	1.23029E-12\$
-	122,	102,	6100,	1.07898E-12\$
-	123,	102,	6101,	8.69266E-13\$
-	124,	102,	6102,	1.77327E-12\$
-	125,	102,	6103,	4.21757E-12\$
-	126,	102,	6104,	1.52994E-11\$
-	127,	102,	6105,	1.22987E-12\$
-	128,	102,	10400,	6.21930E-12\$
-	129,	102,	10500,	1.55560E-12\$
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-	132,	103,	105,	2.09906E-12\$
-	133,	103,	2100,	1.60315E-12\$
-	134,	103,	2101,	1.20506E-12\$
-	135,	103,	2102,	4.03306E-12\$
-	136,	103,	2103,	1.10967E-11\$
-	137,	103,	2104,	4.27658E-12\$
-	138,	103,	2105,	2.09982E-12\$
-	139,	103,	4100,	1.60315E-12\$
-	140,	103,	4101,	1.20506E-12\$

-	141,	103,	4102,	4.27647E-12\$
-	142,	103,	4103,	1.10967E-11\$
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-	144,	103,	4105,	2.09982E-12\$
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-	146,	103,	6101,	1.21375E-12\$
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-	152,	103,	10500,	2.65501E-12\$
-	153,	103,	10600,	2.11244E-12\$
-	154,	104,	105,	1.26452E-12\$
-	155,	104,	2100,	1.15642E-12\$
-	156,	104,	2101,	8.98014E-13\$
-	157,	104,	2102,	1.52791E-11\$
-	158,	104,	2103,	4.50646E-12\$
-	159,	104,	2104,	1.79708E-12\$
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-	161,	104,	4100,	1.15642E-12\$
-	162,	104,	4101,	7.96158E-13\$
-	163,	104,	4102,	1.79706E-12\$
-	164,	104,	4103,	4.50646E-12\$
-	165,	104,	4104,	1.70296E-12\$
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-	167,	104,	6100,	1.15642E-12\$
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-	169,	104,	6102,	1.85571E-12\$
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-	171,	104,	6104,	1.77335E-12\$
-	172,	104,	6105,	1.26452E-12\$
-	173,	104,	10400,	6.50639E-12\$
-	174,	104,	10500,	1.59944E-12\$
-	175,	104,	10600,	1.52380E-12\$
-	176,	105,	2100,	4.44002E-13\$
-	177,	105,	2101,	1.93978E-12\$
-	178,	105,	2102,	1.19843E-12\$
-	179,	105,	2103,	2.09902E-12\$
-	180,	105,	2104,	1.24027E-12\$
-	181,	105,	2105,	6.57195E-12\$
-	182,	105,	4100,	4.44002E-13\$
-	183,	105,	4101,	1.93978E-12\$
-	184,	105,	4102,	1.24027E-12\$
-	185,	105,	4103,	2.09901E-12\$
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-	188,	105,	6100,	4.44002E-13\$
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-	190,	105,	6102,	1.26452E-12\$
-	191,	105,	6103,	2.09898E-12\$
-	192,	105,	6104,	1.22987E-12\$
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-	196,	105,	10600,	5.85054E-13\$
-	197,	2100,	2101,	2.53408E-12\$
-	198,	2100,	2102,	1.10186E-12\$
-	199,	2100,	2103,	1.80075E-12\$
-	200,	2100,	2104,	1.08759E-12\$
-	201,	2100,	2105,	4.44396E-13\$
-	202,	2100,	4100,	6.33910E-12\$
-	203,	2100,	4101,	2.53408E-12\$
-	204,	2100,	4102,	1.08759E-12\$
-	205,	2100,	4103,	1.80074E-12\$
-	206,	2100,	4104,	1.10187E-12\$
-	207,	2100,	4105,	4.44396E-13\$
-	208,	2100,	6100,	6.33910E-12\$
-	209,	2100,	6101,	2.62294E-12\$

-	210,	2100,	6102,	1.15644E-12s
-	211,	2100,	6103,	1.60309E-12s
-	212,	2100,	6104,	1.07898E-12s
-	213,	2100,	6105,	4.44002E-13s
-	214,	2100,	10400,	2.36490E-12s
-	215,	2100,	10500,	5.61598E-13s
-	216,	2100,	10600,	8.35294E-12s
-	217,	2101,	2102,	7.61413E-13s
-	218,	2101,	2103,	1.28078E-12s
-	219,	2101,	2104,	7.67950E-13s
-	220,	2101,	2105,	1.95289E-12s
-	221,	2101,	4100,	2.53408E-12s
-	222,	2101,	4101,	2.12277E-11s
-	223,	2101,	4102,	8.65596E-13s
-	224,	2101,	4103,	1.28078E-12s
-	225,	2101,	4104,	7.54567E-13s
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-	227,	2101,	6100,	2.53408E-12s
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-	229,	2101,	6102,	7.96181E-13s
-	230,	2101,	6103,	1.20502E-12s
-	231,	2101,	6104,	7.56849E-13s
-	232,	2101,	6105,	1.93978E-12s
-	233,	2101,	10400,	1.71202E-12s
-	234,	2101,	10500,	2.45355E-12s
-	235,	2101,	10600,	3.33911E-12s
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-	237,	2102,	2104,	1.64889E-12s
-	238,	2102,	2105,	1.19884E-12s
-	239,	2102,	4100,	1.10186E-12s
-	240,	2102,	4101,	7.54563E-13s
-	241,	2102,	4102,	1.64886E-12s
-	242,	2102,	4103,	4.12052E-12s
-	243,	2102,	4104,	1.56324E-12s
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-	245,	2102,	6100,	1.10186E-12s
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-	248,	2102,	6103,	4.03291E-12s
-	249,	2102,	6104,	1.62722E-12s
-	250,	2102,	6105,	1.19843E-12s
-	251,	2102,	10400,	5.94608E-12s
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-	253,	2102,	10600,	1.45191E-12s
-	254,	2103,	2104,	4.36731E-12s
-	255,	2103,	2105,	2.09979E-12s
-	256,	2103,	4100,	1.80075E-12s
-	257,	2103,	4101,	1.28078E-12s
-	258,	2103,	4102,	4.36720E-12s
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-	260,	2103,	4104,	4.12079E-12s
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-	262,	2103,	6100,	1.80075E-12s
-	263,	2103,	6101,	1.29203E-12s
-	264,	2103,	6102,	4.50637E-12s
-	265,	2103,	6103,	1.10963E-11s
-	266,	2103,	6104,	4.30745E-12s
-	267,	2103,	6105,	2.09902E-12s
-	268,	2103,	10400,	1.64093E-11s
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-	270,	2103,	10600,	2.37282E-12s
-	271,	2104,	2105,	1.24070E-12s
-	272,	2104,	4100,	1.08759E-12s
-	273,	2104,	4101,	8.65158E-13s
-	274,	2104,	4102,	1.53450E-11s
-	275,	2104,	4103,	4.36731E-12s
-	276,	2104,	4104,	1.64900E-12s
-	277,	2104,	4105,	1.24070E-12s
-	278,	2104,	6100,	1.08759E-12s

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-	280,	2104,	6102,	1.79707E-12\$
-	281,	2104,	6103,	4.27642E-12\$
-	282,	2104,	6104,	1.71749E-12\$
-	283,	2104,	6105,	1.24027E-12\$
-	284,	2104,	10400,	6.30636E-12\$
-	285,	2104,	10500,	1.56876E-12\$
-	286,	2104,	10600,	1.43310E-12\$
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-	294,	2105,	6101,	1.95607E-12\$
-	295,	2105,	6102,	1.26496E-12\$
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-	297,	2105,	6104,	1.23029E-12\$
-	298,	2105,	6105,	6.57195E-12\$
-	299,	2105,	10400,	2.85274E-12\$
-	300,	2105,	10500,	8.31258E-12\$
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-	303,	4100,	4102,	1.08759E-12\$
-	304,	4100,	4103,	1.80074E-12\$
-	305,	4100,	4104,	1.10187E-12\$
-	306,	4100,	4105,	4.44396E-13\$
-	307,	4100,	6100,	6.33910E-12\$
-	308,	4100,	6101,	2.62294E-12\$
-	309,	4100,	6102,	1.15644E-12\$
-	310,	4100,	6103,	1.60309E-12\$
-	311,	4100,	6104,	1.07898E-12\$
-	312,	4100,	6105,	4.44002E-13\$
-	313,	4100,	10400,	2.36490E-12\$
-	314,	4100,	10500,	5.61598E-13\$
-	315,	4100,	10600,	8.35294E-12\$
-	316,	4101,	4102,	7.67944E-13\$
-	317,	4101,	4103,	1.28078E-12\$
-	318,	4101,	4104,	7.61429E-13\$
-	319,	4101,	4105,	1.95290E-12\$
-	320,	4101,	6100,	2.53408E-12\$
-	321,	4101,	6101,	2.12621E-11\$
-	322,	4101,	6102,	8.98462E-13\$
-	323,	4101,	6103,	1.20502E-12\$
-	324,	4101,	6104,	7.54841E-13\$
-	325,	4101,	6105,	1.93979E-12\$
-	326,	4101,	10400,	1.71202E-12\$
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-	330,	4102,	4104,	1.64896E-12\$
-	331,	4102,	4105,	1.24070E-12\$
-	332,	4102,	6100,	1.08759E-12\$
-	333,	4102,	6101,	7.71038E-13\$
-	334,	4102,	6102,	1.79701E-12\$
-	335,	4102,	6103,	4.27631E-12\$
-	336,	4102,	6104,	1.71745E-12\$
-	337,	4102,	6105,	1.24027E-12\$
-	338,	4102,	10400,	6.30620E-12\$
-	339,	4102,	10500,	1.56876E-12\$
-	340,	4102,	10600,	1.43310E-12\$
-	341,	4103,	4104,	4.12079E-12\$
-	342,	4103,	4105,	2.09979E-12\$
-	343,	4103,	6100,	1.80074E-12\$
-	344,	4103,	6101,	1.29203E-12\$
-	345,	4103,	6102,	4.50637E-12\$
-	346,	4103,	6103,	1.10963E-11\$
-	347,	4103,	6104,	4.30745E-12\$

-	348,	4103,	6105,	2.09902E-12\$
-	349,	4103,	10400,	1.64093E-11\$
-	350,	4103,	10500,	2.65495E-12\$
-	351,	4103,	10600,	2.37281E-12\$
-	352,	4104,	4105,	1.19887E-12\$
-	353,	4104,	6100,	1.10187E-12\$
-	354,	4104,	6101,	8.69125E-13\$
-	355,	4104,	6102,	1.52791E-11\$
-	356,	4104,	6103,	4.03318E-12\$
-	357,	4104,	6104,	1.62731E-12\$
-	358,	4104,	6105,	1.19846E-12\$
-	359,	4104,	10400,	5.94649E-12\$
-	360,	4104,	10500,	1.51588E-12\$
-	361,	4104,	10600,	1.45191E-12\$
-	362,	4105,	6100,	4.44396E-13\$
-	363,	4105,	6101,	1.95607E-12\$
-	364,	4105,	6102,	1.26496E-12\$
-	365,	4105,	6103,	2.09975E-12\$
-	366,	4105,	6104,	1.23029E-12\$
-	367,	4105,	6105,	6.57196E-12\$
-	368,	4105,	10400,	2.85274E-12\$
-	369,	4105,	10500,	8.31258E-12\$
-	370,	4105,	10600,	5.85574E-13\$
-	371,	6100,	6101,	2.62294E-12\$
-	372,	6100,	6102,	1.15644E-12\$
-	373,	6100,	6103,	1.60309E-12\$
-	374,	6100,	6104,	1.07898E-12\$
-	375,	6100,	6105,	4.44002E-13\$
-	376,	6100,	10400,	2.36490E-12\$
-	377,	6100,	10500,	5.61598E-13\$
-	378,	6100,	10600,	8.35294E-12\$
-	379,	6101,	6102,	8.11779E-13\$
-	380,	6101,	6103,	1.21370E-12\$
-	381,	6101,	6104,	7.71620E-13\$
-	382,	6101,	6105,	1.94296E-12\$
-	383,	6101,	10400,	1.72480E-12\$
-	384,	6101,	10500,	2.45757E-12\$
-	385,	6101,	10600,	3.45621E-12\$
-	386,	6102,	6103,	4.41155E-12\$
-	387,	6102,	6104,	1.77332E-12\$
-	388,	6102,	6105,	1.26452E-12\$
-	389,	6102,	10400,	6.50625E-12\$
-	390,	6102,	10500,	1.59944E-12\$
-	391,	6102,	10600,	1.52383E-12\$
-	392,	6103,	6104,	4.21768E-12\$
-	393,	6103,	6105,	2.09898E-12\$
-	394,	6103,	10400,	1.61019E-11\$
-	395,	6103,	10500,	2.65491E-12\$
-	396,	6103,	10600,	2.11236E-12\$
-	397,	6104,	6105,	1.22987E-12\$
-	398,	6104,	10400,	6.21947E-12\$
-	399,	6104,	10500,	1.55561E-12\$
-	400,	6104,	10600,	1.42176E-12\$
-	401,	6105,	10400,	2.85167E-12\$
-	402,	6105,	10500,	8.31038E-12\$
-	403,	6105,	10600,	5.85054E-13\$
-	404,	10400,	10500,	3.60696E-12\$
-	405,	10400,	10600,	3.11619E-12\$
-	406,	10500,	10600,	7.40009E-13\$

REM

REM

END

REM *****

BCD 3CONSTANTS DATA

REM *****

REM

1, 62.5 \$ POWER DISSIPATION PER PELLET (WATTS)
 NDI=5000,ARLXCA=.05,DRLXCA=.05,NLOOP=1000
 BALENG=4.26

```

END
REM *****
BCD JARRAY DATA
REM *****
REM
REM      ** FUEL PELLET K(BTU/FT-HR-F) VS. T(F) **
1, -1000., .242, 100., .242, 572., .254, 752., .266
   932., .315, 1112., .325, 1292., .335, 1472., .545
   1652., .59, 1832., .635, 2012., .681, 2192., .726
   2500., .747, 3000., .78, 3500., .814, 4000., .848
   5000., .915, 20000., .915, END
REM      ** IRIIDIUM CLADING K(BTU/FT-HR-F) VS. T(F) **
2, -1000., 85., 0., 85., 1000., 79., 2000., 76.5
   3000., 65.5, 4000., 65., 20000., 65., END
REM      ** GIS SIDES K(BTU/FT-HR-F) VS. T(F) **
3, -1000., 98.8, 0., 98.8, 500., 75.8, 750., 67.1
   1000., 59.6, 1250., 53.3, 1500., 48.3, 1750., 44.2
   2000., 40., 2500., 35., 3000., 30.8, 4000., 27.9
   4800., 26.6, 20000., 26.6, END
REM      * GIS END SECTION W/ HOLES K(BTU/FT-HR-F) VS. T(F) *
4, -1000., 63.8, 0., 63.8, 500., 49.7, 750., 44.
   1000., 38.7, 1250., 40.2, 1500., 30.9, 1750., 28.2
   2000., 26.2, 2500., 23.3, 3000., 22., 4000., 20.6
   7800., 20., 20000., 20., END
REM      ** FLOATING MEMBRANE K(BTU/FT-HR-F) VS. T(F) **
5, -1000., 49.3, 100., 49.3, 500., 40.2, 750., 35.5
   1000., 31.2, 1250., 27.8, 1500., 25., 1750., 22.8
   2000., 21.1, 2500., 18.8, 3000., 17.8, 4000., 16.7
   4800., 16.1, 20000., 16.1, END
REM      ** CBCF SLEEVE K(BTU/FT-HR-F) VS. T(F) **
6, -1000., .03545, 0., .03545, 392., .052, 572., .061
   752., .071, 932., .081, 1112., .086, 1292., .091
   1472., .096, 1652., .101, 1832., .107, 2012., .112
   2192., .117, 2372., .122, 2552., .128, 3000., .141
   4000., .171, 10000., .7, END
REM      ** AEROSHELL X,Y DIR K(BTU/FT-HR-F) VS. T(F) **
7, -1000., 98.8, 0., 98.8, 500., 75.8, 750., 67.1
   1000., 59.6, 1250., 53.3, 1500., 48.3, 1750., 44.2
   2000., 40.0, 2500., 35.0, 3000., 30.8, 4000., 27.9
   4800., 26.6, 20000., 26.6, END
REM      ** AEROSHELL Z DIR K(BTU/FT-HR-F) VS. T(F) **
8, -1000., 77.4, 0., 77.4, 500., 60.3, 750., 53.3
   1000., 46.9, 1250., 41.7, 1500., 37.5, 1750., 34.2
   2000., 31.7, 2500., 28.3, 3000., 26.7, 4000., 25.
   4800., 24.2, 20000., 24.2, END
REM      ** "SCRIPT F" VS. T(F), PELLET-TO-CLADDING **
11, -1000., .0794, 0., .0794, 1000., .129, 2000., .181
   3000., .236, 4000., .294, 20000., .603, END
REM      ** "SCRIPT F" VS. T(F), CLADDING-TO-GIS SIDES **
12, -1000., .0822, 0., .0822, 1000., .133, 2000., .184
   3000., .235, 4000., .285, 20000., .620, END
REM      ** "SCRIPT F" VS. T(F), CLADDING-TO-GIS ENDS **
13, -1000., .0812, 0., .0812, 1000., .132, 2000., .183
   3000., .235, 4000., .287, 20000., .620, END
REM      * "SCRIPT F" VS. T(F), CLADDING-TO-FLOATING MEMBRANE *
14, -1000., .0812, 0., .0812, 1000., .132, 2000., .183
   3000., .235, 4000., .287, 20000., .620, END
REM      ** "SCRIPT F" VS. T(F), FLOATING MEMBRANE-TO-GIS **
15, -1000., .617, 0., .617, 500., .637, 750., .647
   1000., .657, 1250., .666, 1500., .669, 1750., .686
   2000., .696, 2500., .717, 3000., .738, 4000., .778
   4800., .813, 20000., 1., END
REM      ** "SCRIPT F" VS. T(F), GIS SIDES-TO-CBCF SLEEVE **
16, -1000., .675, 0., .675, 500., .676, 750., .678
   1000., .679, 1250., .681, 1500., .683, 1750., .686
   2000., .689, 2500., .694, 3000., .700, 4000., .711
   20000., .8, END
REM      ** "SCRIPT F" VS. T(F), GIS ENDS-TO-CBCF SLEEVE **
17, -1000., .610, 0., .610, 500., .628, 750., .637

```



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1000., .645, 1250., .652, 1500., .659, 1750., .667
2000., .674, 2500., .688, 3000., .702, 4000., .725
7800., .743, 20000., .8, END
REM * "SCRIPT F" VS. T(F), CBCF SLEEVE-TO-AEROSHELL TOP & BOTTOM*
18, -1000., .553, 0., .553, 500., .578, 750., .593
1000., .607, 1250., .620, 1500., .633, 1750., .646
2000., .658, 2500., .680, 3000., .703, 4000., .738
4800., .763, 20000., .8, END
REM * "SCRIPT F" VS. T(F), CBCF SLEEVE-TO-AEROSHELL SIDES *
19, -1000., .675, 0., .675, 500., .676, 750., .678
1000., .679, 1250., .681, 1500., .683, 1750., .686
2000., .689, 2500., .694, 3000., .700, 4000., .711
4800., .723, 20000., .8, END
REM ** EMISSIVITY VS. T(F), AEROSHELL X,Y DIRECTION **
20, -1000., .812, 0., .812, 500., .814, 750., .816
1000., .818, 1250., .821, 1500., .824, 1750., .828
2000., .832, 2500., .84, 3000., .848, 4000., .865
4800., .882, 20000., 1., END
REM ** EMISSIVITY VS. T(F), AEROSHELL Z DIRECTION **
21, -1000., .642, 0., .642, 500., .675, 750., .696
1000., .716, 1250., .734, 1500., .752, 1750., .77
2000., .788, 2500., .82, 3000., .853, 4000., .905
4800., .943, 20000., 1., END

```

```

END
REM
REM *****
BCD 3EXECUTION
REM *****

```

```

STDSTL
END
REM *****
BCD 3VARIABLES 1
REM *****
REM

```

```

REM STORE POWER DISSIPATIONS

```

```

M Q600 = XK1 * 3.412 / 3.
M Q601 = XK1 * 3.412 / 3.
M Q605 = XK1 * 3.412 / 3.
M Q625 = XK1 * 3.412 / 3.
M Q626 = XK1 * 3.412 / 3.
M Q630 = XK1 * 3.412 / 3.
M Q1600 = XK1 * 3.412 / 3.
M Q1601 = XK1 * 3.412 / 3.
M Q1605 = XK1 * 3.412 / 3.
M Q1625 = XK1 * 3.412 / 3.
M Q1626 = XK1 * 3.412 / 3.
M Q1630 = XK1 * 3.412 / 3.
M Q2600 = XK1 * 3.412 / 3.
M Q2601 = XK1 * 3.412 / 3.
M Q2605 = XK1 * 3.412 / 3.
M Q2625 = XK1 * 3.412 / 3.
M Q2626 = XK1 * 3.412 / 3.
M Q2630 = XK1 * 3.412 / 3.
M Q3600 = XK1 * 3.412 / 3.
M Q3601 = XK1 * 3.412 / 3.
M Q3605 = XK1 * 3.412 / 3.
M Q3625 = XK1 * 3.412 / 3.
M Q3626 = XK1 * 3.412 / 3.
M Q3630 = XK1 * 3.412 / 3.
M Q4600 = XK1 * 3.412 / 3.
M Q4601 = XK1 * 3.412 / 3.
M Q4605 = XK1 * 3.412 / 3.
M Q4625 = XK1 * 3.412 / 3.
M Q4626 = XK1 * 3.412 / 3.
M Q4630 = XK1 * 3.412 / 3.
M Q5600 = XK1 * 3.412 / 3.
M Q5601 = XK1 * 3.412 / 3.
M Q5605 = XK1 * 3.412 / 3.
M Q5625 = XK1 * 3.412 / 3.

```

```

M      Q5626 = XK1 * 3.412 / 3.
M      Q5630 = XK1 * 3.412 / 3.
M      Q6600 = XK1 * 3.412 / 3.
M      Q6601 = XK1 * 3.412 / 3.
M      Q6605 = XK1 * 3.412 / 3.
M      Q6625 = XK1 * 3.412 / 3.
M      Q6626 = XK1 * 3.412 / 3.
M      Q6630 = XK1 * 3.412 / 3.
M      Q7600 = XK1 * 3.412 / 3.
M      Q7601 = XK1 * 3.412 / 3.
M      Q7605 = XK1 * 3.412 / 3.
M      Q7625 = XK1 * 3.412 / 3.
M      Q7626 = XK1 * 3.412 / 3.
M      Q7630 = XK1 * 3.412 / 3.
      END
      REM *****
      BCD 3VARIABLES 2
      REM *****
      END
      REM *****
      BCD 3OUTPUT CALLS
      REM *****
      QIPRNT
      TPRINT
      END
      BCD 3END OF DATA

```

National Aeronautics and
Space Administration

Report Documentation Page

1. Report No. CR187145	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Thermal Analysis of Conceptual Designs for GPHS/FPSE Power Systems of 250 W and 500 W		5. Report Date March 1991
		6. Performing Organization Code
7. Author(s) Thomas J. McComas and Edward T. Dugan		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address University of Florida Department of Nuclear Engineering Sciences Gainesville, Florida		11. Contract or Grant No. NAG3-1123
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15. Supplementary Notes Project Manager, Colleen Withrow, Power Technology Division, NASA Lewis Research Center.		
16. Abstract Thermal analyses were performed for two distinct configurations of a proposed space nuclear power system which combines the U.S. Department of Energy's (DOE) General Purpose Heat Source (GPHS) modules with state-of-the-art Free-Piston Stirling Engines (FPSE). The two configurations correspond to systems with power levels of 250 W _e and 500 W _e . The 250 W _e GPHS/FPSE power system utilizes four GPHS modules and one FPSE, and the 500 W _e contains eight GPHS modules and two FPSEs. The configurations of the systems and the bases for selecting the configurations are described. Brief introductory sections are included to describe the GPHS modules and free-piston Stirling engines. The primary focus of the thermal analyses is on the temperature of the iridium fuel clad within the GPHS modules. A design goal temperature of 1573 K has been selected as upper limit for the fuel clad during normal operating conditions. The basis for selecting this temperature limit is discussed in detail. Results obtained from thermal analysis of the 250 W _e GPHS/FPSE power system indicate fuel clad temperatures which slightly exceed the design goal temperature of 1573 K. The results are considered favorable due to the numerous conservative assumptions used in developing the thermal model and performing the thermal analysis. To demonstrate the effects of the conservatism, a brief sensitivity analysis is performed in which a few of the key system parameters are varied to determine their effect on the fuel clad temperatures. It is concluded that thermal analysis of a more detailed thermal model would be expected to yield fuel clad temperatures below the design goal temperature limit of 1573 K.		
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